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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	SON-1648/CON	*Total Pages*	157
First Named Inventor or Application Identifier	Junji HORIKAWA, et al.		
Express Mail Label No.			

APPLICATION ELEMENTS

See MPEP Chapter 600 concerning utility patent application contents

ADDRESS TO: Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

1. [X] Fee Transmittal Form *(Submit an original, and a duplicate for fee processing)*
2. [X] Specification *[Total Pages* 45 *(preferred arrangement set forth below)*
   - Descriptive title of the Invention
   - Cross References to Related Applications
   - Statement Regarding Fed sponsored R&D
   - Reference to Microfiche Appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings *(if filed)*
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
3. [X] Drawing(s) *(35 USC d113)* *[Total Sheets* 15
4. Oath or Declaration *[Total Pages* 2
   a. [ ] Newly Executed (original or copy)
   b. [X] Copy from a prior application (37 CFR 1.63(d)) *(for continuation/divisional with Box 17 completed)*
   [Note Box 5 below]
   i. [ ] DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(2) and 1 33(b).
5. [ ] Incorporation By Reference *(useable if Box 4b is checked)* The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.
6. [ ] Microfiche Computer Program *(Appendix)*
7. Nucleotide and/or Amino Acid Sequence Submission *(if applicable, all necessary)*
   a. [ ] Computer Readable Copy
   b. [ ] Paper Copy (identical to computer copy)
   c. [ ] Statement verifying identical of above copies

ACCOMPANYING APPLICATION PARTS

8. [ ] Assignment Papers (cover sheet & Documents(s))
9. [ ] 37 CFR 3.27(B) Statement *(when there is an assignee)* [ ] Power of Attorney
10. [ ] English Translation Document *(if applicable)*
11. [ ] Information Disclosure Statement (IDS)/PTO-1449 [ ] Copies of IDS Citations
12. [X] Preliminary Amendment
13. [X] Return Receipt Postcard (MPEP 503) *(Should be specifically itemized)*
14. [ ] Small Entity Statement(s) [ ] Statement filed in prior application Status still proper and desired
15. [ ] Certified Copy of Priority Document(s) *if foreign priority is claimed)*
16. [X] Other: 15 Sheets of New Formal Drawings (Fig. 1 through Fig. 15); and Substitute Specification

17. If a CONTINUING APPLICATION, *check appropriate box and supply the requisite information*

☒Continuation ☐Divisional ☐Continuation-in-part (CIP) of prior application No: 08/755,129

18. CORRESPONDENCE ADDRESS

[ ] *Customer Number or Bar Code Label* or [X] *Correspondence address below*

NAME	**Ronald P. Kananen** **Registration No. 24,104**				
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REQUEST FORM FOR CONTINUATION/DIVISION APPLICATION UNDER 37 CFR 1.53(b)

Docket No. SON-1648/CON
File No. 80001-1648
Prior Application: 08/755,129
Prior Examiner A. DO
Prior Group Art Unit 2724

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

This is a request for filing a continuation application, under 37 CFR 1.53(b) of pending prior application Serial No 08/755,129 filed on November 25, 1996 of Junji HORIKAWA, et al. entitled COMPUTER ANIMATION GENERATOR.

1. ☒ Enclosed is a true copy of prior application Serial No. 08/755,129 including the Declaration and Power of Attorney, as originally filed on November 25, 1996 .

2. ☒ An issue fee payment was submitted in the prior application on 07/27/99 , a copy of which is enclosed.

3a. ☒ The filing fee is calculated below:

CLAIMS AS FILED IN THE PRIOR APPLICATION, PLUS OR MINUS ANY CLAIMS ADDED OR CANCELLED BY AMENDMENT BELOW						
	NUMBER FILED		(4) HIGHEST NO. PREVIOUSLY PAID FOR	(5) NUMBER EXTRA	RATE	BASIC FILING FEE $760/$380
Total Claims	*117	Minus	**20	= 97	x $9° $18	1,746.00
Indep. Claims	*5	Minus	***3	= 2	x $39° $78	156.00
Fee for Multiple Dependent Claims					$135° $270	
			TOTAL ADDITIONAL FEE FOR THIS AMENDMENT			2,662.00

* If the entry in Column 2 is less than the entry in Column 4, write "0" in Column 5.

** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, write "20" in this space.

*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, write "3" in this space.

3b. ☐ The present application is filed by a small entity (37 C.F.R. § 1.9(f)). A Verified Statement claiming small entity status was filed in the prior application.

3c. ☒ Any prior general authorization to charge an issue fee under 37 C.F.R. 1.18 to Deposit Account No. 18-0013 is hereby revoked. The Commissioner is hereby authorized to charge any fees which may be required during the entire pendency of this application under 37 CFR 1.16 and 1.17, or to credit any overpayment, to Deposit Account No. 18-0013. A duplicate copy of this sheet is enclosed.

4a. ☒ Charge $ 2,662.00 to Deposit Account No. 18-0013. A duplicate copy of this sheet is enclosed.

5. ☒ Cancel in this application original claims 2 to 19 of the prior application before calculating the filing fee. (At least one original independent claim must be retained for filing purposes.)

6. ☒ Amend the specification by inserting before the first line the sentence: --This application is a continuation of application Serial No 08/755,129 filed November 25, 1996.

7a. ☐ Transfer the drawings from the prior application to this application and abandon said prior application as of the filing date accorded this application. A duplicate copy of this sheet is enclosed for filing in the prior application file.

7b. ☒ New ☒ formal ☐ informal drawings are enclosed.

8a. ☒ Priority of the following application(s) is claimed under 35 U.S.C. § 119:

Country	Application No.	Filed (Mo., Day & Yr.)
Japan	P07-348403	December 18, 1995

8b. ☒ The certified copy of the priority applications have been filed in prior U.S. Application Serial No. 08/755,129 , filed November 25, 1996 .

9. ☒ The prior application is assigned of record to: Sony Corporation

10. ☒ The power of attorney in the prior application is to: Richard Linn, Registration No. 25,144; Ronald P. Kananen, Registration No. 24,104, Michael D. Bednarek, Registration No. 32,329, George T. Marcou, Registration No. 33,014, George C. Beck, Registration No. 38,072, Richard T. Peterson, Registration No. 35,320 and Jeffrey L. Thompson, Registration No. 37,025.

11a. ☒ The power appears in the original papers in prior application Serial No. 08/755,129 .

11b. ☐ Since the power does not appear in the original papers, a copy of the power in prior application Serial No. ________________ is enclosed.

11c. ☒ Recognize as Associate Attorneys: Ralph T. Rader, Registration No. 28,772; Michael D. Fishman, Registration No. 31,952; Richard D. Grauer, Registration No. 22,388; Michael B. Stewart, Registration No. 36,018; Steven L. Nichols, Registration No. 40,326, and David K. Benson, Reg. No. 42,314.

11d. ☒ Applicants' undersigned attorney may be reached by telephone in our Washington D.C. Office at

(202) 955-3750

11e. ☒ Address all future communications to:

Ronald P. Kananen
Rader, Fishman & Grauer P.L.L.C.
1223 20th Street, N.W.
Suite 501
Washington, D.C. 20036

12a. ☒ A preliminary amendment is enclosed. (Claims added by this amendment have been properly numbered consecutively beginning with the number next following the highest numbered original claim.)

12b. ☐ The applicant(s) presently intend(s) to file additional papers in this case after receiving an official Filing Receipt. Should the Examiner take this case up for action before receiving such papers, it is respectfully requested that the Examiner contact the attorneys for the applicant(s) at the telephone number shown above.

Date: August 4, 1999

Ronald P. Kananen
Reg. No. 24,104

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DC027117.DOC

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Patent Application of)
Junji HORIKAWA, et al.) Prior Art Unit: 2724
Serial No. Not Assigned) Prior Examiner: A. DO
Filed: Herewith)
For: Computer Animation Generator)

PRELIMINARY AMENDMENT

Assistant Commissioner of Patents
Washington, DC 20231

Sir:

Prior to the initial examination, please amend the above-identified application as follows:

IN THE CLAIMS

Please cancel original claims 1 to 19.

Please add the following new claims in place thereof.

20. (new) A method of approximating an image by decreasing an amount of image data used to create the image, wherein said image data defines a polygonal framework, said framework being composed of line segments drawn between vertices, said method comprising:

evaluating a degree of importance of each line segment of said framework;

removing at least one unnecessary line segment from said framework which is identified based on said evaluation of said degree of importance of each line segment; and

determining a position of a vertex after said unnecessary line segment is removed.

21. (new) The method of claim 20, wherein said image data defines a 3-dimensional polygonal framework.

22. (new) The method of claim 20, wherein said evaluating a degree of importance of each line segment is performed by evaluating an amount by which a volume of the polygonal framework defined by the image data is changed by removal of a particular line segment.

23. (new) The method of claim 22, wherein said evaluating a degree of importance of each line segment further comprises assigning a line segment a degree of importance in direct proportion to the amount of volume change caused by removal of that line segment.

24. (new) The method of claim 20, wherein said evaluating a degree of importance of each line segment is performed using a vector (E) which represents a particular

line segment, an area (A) of a polygon within said polygonal framework wherein said particular line segment is a side of said polygon, and a vector (N) normal to a plane of said polygon.

25. (new) The method of claim 24,

wherein said evaluating a degree of importance of each line segment further comprises calculating an importance of a particular line segment by $(N \bullet E) \times A$,

wherein E is said vector representing a particular line segment, A is said area of a polygon sided by said particular line segment, and N is said normal vector.

26. (new) The method of claim 20, wherein said evaluating a degree of importance of each line segment is performed based on an amount by which an area of said polygonal framework defined by said image data is changed by removal of a particular line segment.

27. (new) The method of claim 26, wherein said evaluating a degree of importance of each line segment further comprises assigning a degree of importance to a particular line segment in direct proportion to said amount by which said

area of said polygonal framework is changed by removal of that line segment.

28. (new) The method of claim 20, wherein said evaluating a degree of importance of each line segment is performed based on a length of a particular line segment and an area of a polygon within said polygonal framework of which said particular line segment is a side.

29. (new) The method of claim 28, wherein said evaluating a degree of importance of each line segment further comprises calculating a sum of results of an equation $|E| \times A$ for polygons sided by said particular line segment, wherein "$|E|$" is length of that line segment, "A" is an area of a polygon sided by said particular line segment.

30. (new) The method of claim 20, wherein said evaluating a degree of importance of each line segment is performed based on a length of said line segments.

31. (new) The method of claim 30, wherein said evaluating a degree of importance of said line segments further comprises assigning a degree of importance to each

line segment in direct proportion to a length of that line segment.

32. (new) The method of claim 20, wherein if two or more line segments are assigned an identical degree of importance, said method further comprises assigning a lowest degree of importance among said two or more line segments to that line segment of said two or more line segments with a shortest length.

33. (new) The method of claim 20, further comprising repeating said steps of evaluating a degree of importance of each line segment; removing an unnecessary line segment; and determining a position of a vertex after said unnecessary line segment is removed.

34. (new) The method of claim 20, wherein said evaluating a degree of importance of each line segment is performed based on an amount by which an amount of said image data is changed by removal of a particular line segment.

35. (new) The method of claim 20, wherein said evaluating a degree of importance of each line segment is

performed based on importance values assigned by a user to one or more of said line segments.

36. (new) The method of claim 35, further comprising specifying one or more of said line segments as of high importance, wherein said evaluating a degree of importance of each line segment further comprises preventing said one or more high importance line segments from being designated as said unnecessary line segment.

37. (new) The method of claim 20, wherein said determining a position of a vertex after said unnecessary line segment is removed comprises positioning a vertex at a position such that a total loss of area between a framework including said unnecessary line and a framework in which said unnecessary line segment is removed is minimized.

38. (new) The method of claim 20, wherein said determining a position of a vertex after said unnecessary line segment is removed comprises positioning a vertex at a position such that a loss of area to said framework caused by removal of said unnecessary line segment is approximately equal for portions of said framework on opposite sides of said vertex.

39. (new) The method of claim 20, wherein said determining a position of a vertex after said unnecessary line segment is removed comprises positioning said vertex at a position corresponding to an end of said removed unnecessary line segment.

40. (new) The method of claim 20, further comprising, generating an intermediate configuration of said image data by decreasing a length of said unnecessary line segment prior to said step of removing said unnecessary line segment.

41. (new) The method of claim 20, further comprising, generating an intermediate polygonal framework between an original framework including said unnecessary line segment and a new framework with said unnecessary line segment removed.

42. (new) The method of claim 41, wherein said generating an intermediate framework comprises locating a vertex an a position intermediate to a vertex position in said original framework and a vertex position determined in said step of determining a position of a vertex after said unnecessary line segment is removed.

43. (new) The method of claim 42, wherein said locating a vertex at an intermediate position comprises using a linear interpolation on said vertex position in said original framework and said vertex position determined in said step of determining a position of a vertex after said unnecessary line segment is removed.

44. (new) The method of claim 20, further comprising reconfiguring a texture applied to said framework to account for said removing of said unnecessary line segment.

45. (new) The method of claim 20, wherein said evaluation of a degree of importance of each line segment is based in part on an evaluation of the degree of importance of line segments contiguous to a particular line segment being evaluated.

46. (new) The method of claim 20, further comprising reconfiguring said framework after said unnecessary line segment has been removed by placing a new vertex at said position identified in said step of determining a position of a vertex.

47. (new) The method of claim 46, wherein said reconfiguring comprises using said new vertex to replace a previous vertex located at an end of said unnecessary, removed line segment.

48. (new) A method of approximating an image by decreasing an amount of image data used to create the image, wherein said image data defines a polygonal framework, said framework being composed of line segments drawn between vertices, said method comprising:

assigning an importance value to each line segment of said framework;

removing from said framework that line segment having a lowest importance value; and

reconfiguring said framework to account for said removal of said line segment having said lowest importance value.

49. (new) The method of claim 48, wherein said reconfiguring further comprises replacing two vertices of said framework, between which said removed line segment had been connected, with a single new vertex.

50. (new) The method of claim 48, wherein said image data defines a 3-dimensional polygonal framework.

51. (new) The method of claim 48, wherein said assigning an importance value to each line segment is performed by evaluating an amount by which a volume of the polygonal framework defined by the image data is changed by removal of a particular line segment.

52. (new) The method of claim 51, wherein said assigning an importance value to each line segment further comprises assigning a line segment an importance value in direct proportion to the amount of volume change caused by removal of that line segment.

53. (new) The method of claim 48, wherein said assigning an importance value to each line segment is performed using a vector (E) which represents a particular line segment, an area (A) of a polygon within said polygonal framework, wherein said particular line segment is a side of said polygon, and a vector (N) normal to a plane of said polygon.

54. (new) The method of claim 53,

wherein said assigning an importance value to each line segment further comprises calculating an importance of a particular line segment by $(N \bullet E) \times A$,

wherein E is said vector representing a particular line segment, A is said area of a polygon sided by said particular line segment, and N is said normal vector.

55. (new) The method of claim 48, wherein said assigning an importance value to each line segment is performed based on an amount by which an area of said polygonal framework defined by said image data is changed by removal of a particular line segment.

56. (new) The method of claim 55, wherein said assigning an importance value to each line segment further comprises assigning an importance value to a particular line segment in direct proportion to said amount by which said area of said polygonal framework is changed by removal of that line segment.

57. (new) The method of claim 48, wherein said assigning an importance value to each line segment is performed based on a length of a particular line segment and

an area of a polygon within said polygonal framework of which said particular line segment is a side.

58. (new) The method of claim 57, wherein said assigning an importance value to each line segment further comprises calculating a sum of results of an equation $|E| \times A$ for polygons sided by said particular line segment, wherein "$|E|$" is length of that line segment, "A" is an area of a polygon sided by said particular line segment.

59. (new) The method of claim 48, wherein said assigning an importance value to each line segment is performed based on a length of said line segments.

60. (new) The method of claim 59, wherein said assigning an importance value to each of said line segments further comprises assigning an importance value to each line segment in direct proportion to a length of that line segment.

61. (new) The method of claim 48, wherein if two or more line segments are assigned an identical degree of importance, said method further comprises assigning a lowest degree of importance among said two or more line segments to

that line segment of said two or more line segments with a shortest length.

62. (new) The method of claim 48, further comprising repeating said steps of assigning an importance value to each line segment; removing that line segment with the lowest importance value; and reconfiguring said framework.

63. (new) The method of claim 48, wherein said assigning an importance value to each line segment is performed based on an amount by which an amount of said image data is changed by removal of a particular line segment.

64. (new) The method of claim 48, wherein said assigning an importance value to each line segment is performed based on importance values assigned by a user to one or more of said line segments.

65. (new) The method of claim 64, further comprising specifying one or more of said line segments as of high importance, wherein assigning an importance value to each line segment further comprises preventing said one or more high importance line segments from being removed.

66. (new) The method of claim 48, wherein said reconfiguring comprises positioning a new vertex at a position such that a total loss of area between a framework including said line segment having said lowest importance value and a framework comprising said new vertex and in which said lowest-importance-value line segment is removed is minimized.

67. (new) The method of claim 48, wherein said reconfiguring comprises positioning a vertex at a position such that a loss of area to said framework caused by removal of said lowest-importance-value line segment is approximately equal for portions of said framework on opposite sides of said vertex.

68. (new) The method of claim 48, wherein said reconfiguring comprises positioning a vertex at a position corresponding to an end of said removed lowest-importance-value line segment.

69. (new) The method of claim 48, further comprising, generating an intermediate configuration of said image data by decreasing a length of said lowest-importance-value line segment prior to said step of removing said lowest-importance-value line segment.

70. (new) The method of claim 48, further comprising, generating an intermediate polygonal framework between an original framework including said lowest-importance-value line segment and a new reconfigured framework with said lowest-importance-value line segment removed.

71. (new) The method of claim 41, wherein said generating an intermediate framework comprises locating a vertex an a position intermediate to a vertex position in said original framework and a new vertex position determined in said step of reconfiguring.

72. (new) The method of claim 71, wherein said locating a vertex at an intermediate position comprises using a linear interpolation on said vertex position in said original framework and said new vertex position determined in said step of reconfiguring.

73. (new) The method of claim 48, further comprising reconfiguring a texture applied to said framework to account for said removing of said lowest-importance-value line segment.

74. (new) The method of claim 48, wherein said assigning an importance value to each line segment is done in accordance with an assigned importance value of line segments contiguous to a particular line segment being evaluated.

75. (new) The method of claim 48, wherein said reconfiguring comprises using a new vertex to replace a previous vertex located at an end of said removed, lowest-importance-value line segment.

76. (new) A method of approximating an image by decreasing an amount of image data used to create the image, wherein said image data defines a polygonal framework formed of polygons to which textures or pictures are applied, said polygons of said framework being composed of line segments connected between vertices, said method comprising:

evaluating a degree of importance of each line segment of said framework;

removing an unnecessary line segment identified by said step of evaluating a degree of importance of each line segment;

reconfiguring said framework to account for said removal of said line segment; and

reconfiguring said textures or pictures applied to said framework to account for said removal of said line segment.

77. (new) The method of claim 76, wherein said reconfiguring the textures or pictures applied to the framework is preformed altering an association between a vertex of said unnecessary line segment and any of said textures or pictures.

78. (new) The method of claim 76, wherein:

said reconfiguring of said framework comprises replacing two vertices of said framework, between which said unnecessary, removed line segment had been connected, with a single new vertex; and

said reconfiguring the textures or pictures applied to the framework comprises determining a new position on said textures or pictures corresponding to a position of said single new vertex in said framework.

79. (new) The method of claim 78, wherein said reconfiguring of said textures or pictures applied to the framework comprises determining said new position by

interpolation between two points on the textures or pictures which correspond to the unnecessary line segment.

80. (new) The method of claim 79, wherein said interpolation is a linear interpolation.

81. (new) The method of claim 76, wherein said evaluating a degree of importance of each line segment of said framework further comprises preventing any line segment existing on an outline of any of said textures or pictures from being designated as said unnecessary line segment.

82. (new) The method of claim 76, wherein said evaluating a degree of importance of each line segment of said framework further comprises preventing any line segment, which exists on an outline of any of said textures or pictures from being designated as said unnecessary line segment if a change in an area of said texture or picture resulting from removal of that line segment exceeds a predetermined value.

83. (new) The method of claim 82, wherein said area change amount after the line segment removal is obtained on the basis of a calculation of sum of results of an equation $|(N \bullet E) \times L|$ at line segments corresponding to the boundary lines

of the texture or picture existing before and after the line segment to be removed, wherein "E" is representing that line segment, "L" is a length of line segment corresponding to the boundary lines of the texture or picture, "N" is a normal vector of said line segments, "•" is a inner product, and "×" is a product.

84. (new) The method of claim 76, wherein said image data defines a 3-dimensional polygonal framework.

85. (new) The method of claim 76, wherein said evaluating a degree of importance of each line segment is performed by evaluating an amount by which a volume of the polygonal framework defined by the image data is changed by removal of a particular line segment.

86. (new) The method of claim 85, wherein said evaluating a degree of importance of each line segment further comprises assigning a line segment a degree of importance in direct proportion to the amount of volume change caused by removal of that line segment.

87. (new) The method of claim 76, wherein said evaluating a degree of importance of each line segment is

performed using a vector (E) which represents a particular line segment, an area (A) of a polygon within said polygonal framework wherein said particular line segment is a side of said polygon, and a vector (N) normal to a plane of said polygon.

88. (new) The method of claim 87,

wherein said evaluating a degree of importance of each line segment further comprises calculating an importance of a particular line segment by $(N \bullet E) \times A$,

wherein E is said vector representing a particular line segment, A is said area of a polygon sided by said particular line segment, and N is said normal vector.

89. (new) The method of claim 76, wherein said evaluating a degree of importance of each line segment is performed based on an amount by which an area of said polygonal framework defined by said image data is changed by removal of a particular line segment.

90. (new) The method of claim 89, wherein said evaluating a degree of importance of each line segment further comprises assigning a degree of importance to a particular line segment in direct proportion to said amount by which said

area of said polygonal framework is changed by removal of that line segment.

91. (new) The method of claim 76, wherein said evaluating a degree of importance of each line segment is performed based on a length of a particular line segment and an area of a polygon within said polygonal framework of which said particular line segment is a side.

92. (new) The method of claim 91, wherein said evaluating a degree of importance of each line segment further comprises calculating a sum of results of an equation $|E| \times A$ for polygons sided by said particular line segment, wherein "$|E|$" is length of that line segment, "A" is an area of a polygon sided by said particular line segment.

93. (new) The method of claim 76, wherein said evaluating a degree of importance of each line segment is performed based on a length of said line segments.

94. (new) The method of claim 93, wherein said evaluating a degree of importance of said line segments further comprises assigning a degree of importance to each

line segment in direct proportion to a length of that line segment.

95. (new) The method of claim 76, wherein if two or more line segments are assigned an identical degree of importance, said method further comprises assigning a lowest degree of importance among said two or more line segments to that line segment of said two or more line segments with a shortest length.

96. (new) The method of claim 76, further comprising repeating said steps of evaluating a degree of importance of each line segment; removing an unnecessary line segment; reconfiguring said framework; and reconfiguring said textures or pictures.

97. (new) The method of claim 76, wherein said evaluating a degree of importance of each line segment is performed based on an amount by which an amount of said image data is changed by removal of a particular line segment.

98. (new) The method of claim 76, wherein said evaluating a degree of importance of each line segment is

performed based on importance values assigned by a user to one or more of said line segments.

99. (new) The method of claim 98, further comprising specifying one or more of said line segments as of high importance, wherein said evaluating a degree of importance of each line segment further comprises preventing said one or more high importance line segments from being designated as said unnecessary line segment.

100. (new) The method of claim 76, wherein said reconfiguring said framework comprises positioning a vertex at a position such that a total loss of area between a framework including said unnecessary line and a framework in which said unnecessary line segment is removed is minimized.

101. (new) The method of claim 76, wherein said reconfiguring said framework comprises positioning a vertex at a position such that a loss of area to said framework caused by removal of said unnecessary line segment is approximately equal for portions of said framework on opposite sides of said vertex.

102. (new) The method of claim 76, wherein said reconfiguring said framework comprises positioning a new vertex at a position corresponding to an end of said removed unnecessary line segment.

103. (new) The method of claim 76, further comprising, generating an intermediate configuration of said image data by decreasing a length of said unnecessary line segment prior to said step of removing said unnecessary line segment.

104. (new) The method of claim 76, further comprising, generating an intermediate polygonal framework between an original framework including said unnecessary line segment and a new framework with said unnecessary line segment removed.

105. (new) The method of claim 104, wherein said generating an intermediate framework comprises locating a vertex an a position intermediate to a vertex position in said original framework and a vertex position determined in said step of determining a position of a vertex after said unnecessary line segment is removed.

106. (new) The method of claim 105, wherein said locating a vertex at an intermediate position comprises using

a linear interpolation on said vertex position in said original framework and said vertex position determined in said step of determining a position of a vertex after said unnecessary line segment is removed.

107. (new) The method of claim 76, wherein said evaluating a degree of importance of each line segment is based in part on an evaluation of a degree of importance of line segments contiguous to a particular line segment being evaluated.

108. (new) The method of claim 76, wherein said reconfiguring said framework comprises using a new vertex to replace a previous vertex located at an end of said unnecessary, removed line segment.

109. (new) A device for use with a display device that approximates an image by decreasing an amount of image data used to create the image, wherein said image data defines a polygonal framework, said framework being composed of line segments drawn between vertices, said device comprising:

a memory unit for storing said image data; and

a processor connected to said memory unit, wherein said processor is programmed to:

(a) assign an importance value to each line segment of said framework;

(b) remove from said framework that line segment having a lowest importance value; and

(c) reconfigure said framework to account for said removal of said line segment having said lowest importance value.

110. (new) The device of claim 109, further comprising an input device inputting said image data to said processor for storage in said memory unit.

111. (new) The device of claim 110, wherein said input device comprises a floppy disk drive.

112. (new) The device of claim 110, wherein said input device comprises a magneto-optical disk drive.

113. (new) The device of claim 109, further comprising a user input device for inputting data to said processor.

114. (new) The device of claim 113, wherein said user input device comprises a keyboard.

115. (new) The device of claim 109, wherein said processor is further programmed to reconfigure texture and pictures applied to said framework to account for removal of said line segment.

116. (new) The device of claim 109, said processor, in performing said reconfiguration of said framework, is programmed to replace two vertices of said framework, between which said removed line segment had been connected, with a single new vertex.

117. (new) The device of claim 109, wherein said image data defines a 3-dimensional polygonal framework.

118. (new) The device of claim 109, said processor, in performing said assignment of importance values, is programmed to evaluating an amount by which a volume of the polygonal framework defined by the image data is changed by removal of a particular line segment.

119. (new) The device of claim 118, said processor, in performing said assignment of importance values, is programmed to assign a line segment an importance value in direct

proportion to the amount of volume change caused by removal of that line segment.

120. (new) The device of claim 109, said processor, in performing said assignment of importance values, is programmed to use a vector (E) which represents a particular line segment, an area (A) of a polygon within said polygonal framework, wherein said particular line segment is a side of said polygon, and a vector (N) normal to a plane of said polygon.

121. (new) The device of claim 120,

wherein said processor assigns an importance value to each line segment by calculating an importance of a particular line segment by $(N \bullet E) \times A$,

wherein E is said vector representing a particular line segment, A is said area of a polygon sided by said particular line segment, and N is said normal vector.

122. (new) The device of claim 109, said processor, in performing said assignment of importance values, is programmed to determine an amount by which an area of said polygonal framework defined by said image data is changed by removal of a particular line segment.

123. (new) The device of claim 122, wherein said processor assigns an importance value to a particular line segment in direct proportion to said amount by which said area of said polygonal framework is changed by removal of that line segment.

124. (new) The device of claim 109, wherein said processor, in performing said assignment of importance values, assigns an importance value to each line segment based on a length of a particular line segment and an area of a polygon within said polygonal framework of which said particular line segment is a side.

125. (new) The device of claim 124, wherein said processor assigns an importance value to each line segment by calculating a sum of results of an equation $|E| \times A$ for polygons sided by said particular line segment, wherein "$|E|$" is length of that line segment, "A" is an area of a polygon sided by said particular line segment.

126. (new) The device of claim 109, wherein said processor, in performing said assignment of importance values,

is programmed to assign an importance value to each line segment based on a length of said line segments.

127. (new) The device of claim 126, wherein said processor assigns an importance value to each line segment in direct proportion to a length of that line segment.

128. (new) The device of claim 109, wherein if two or more line segments are assigned an identical degree of importance, said processor assigns a lowest degree of importance among said two or more line segments to that line segment of said two or more line segments with a shortest length.

129. (new) The device of claim 109, wherein said processor is further programmed to repeat said assignment of an importance value to each line segment; said removal of that line segment with the lowest importance value; and said reconfiguration said framework.

130. (new) The device of claim 109, wherein said processor is programmed to assign an importance value to each line segment based on an amount by which an amount of said image data is changed by removal of a particular line segment.

131. (new) The device of claim 109, wherein said processor is programmed to assign an importance value to each line segment based on importance values assigned by a user to one or more of said line segments.

132. (new) The device of claim 109, wherein said processor is programmed to reconfigure said framework by positioning a new vertex at a position such that a total loss of area between a framework including said line segment having said lowest importance value and a framework containing said new vertex and in which said lowest-importance-value line segment is removed is minimized.

133. (new) The device of claim 109, wherein said processor is programmed to reconfigure said framework by positioning a new vertex at a position such that a loss of area to said framework caused by removal of said lowest-importance-value line segment is approximately equal for portions of said framework on opposite sides of said new vertex.

134. (new) The device of claim 109, wherein said processor is programmed to reconfigure said framework by

positioning a vertex at a position corresponding to an end of said removed lowest-importance-value line segment.

135. (new) The device of claim 109, wherein said processor is programmed to generate an intermediate configuration of said image data by decreasing a length of said lowest-importance-value line segment.

136. (new) The device of claim 109, wherein said processor is programmed to reconfigure said framework by generating a new vertex to replace a previous vertex located at an end of said removed, lowest-importance-value line segment.

REMARKS

This Preliminary Amendment is requested to place the pending claims in a better form for the initial examination.

Additionally, a substitute specification which was accepted in the parent application, U.S. Serial No., 08/755,129, is filed herewith to correct informalities in the specification. The undersigned hereby certifies that no new material has been added.

Entry of this amendment, including the attached substitute specification, is respectfully requested.

Respectfully submitted,

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DATE: August 4, 1999

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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a method and apparatus for hierarchically approximating shape data with an image, in which [a] the data amount is reduced by reducing [a] the complexity of [a] the shape of a geometric model which is used in generating CG (Computer Graphics), thereby enabling the CG to be drawn at a high speed. The invention also relates to a method and apparatus for hierarchically approximating shape data with an image, which is suitable for use in a game using CG, VR (Virtual Reality), designing, and the like since a shape which was approximated so as not to give a sense of incongruity is changed.

Description of the Prior Art

When drawing using a model [by the CG] as part of computer graphics, the same model [is generally always used] may be used repeatedly. For example, as shown in Fig. 14, a detailed original model having data of 100% is formed and the CG is drawn on a display by using it repeatedly. [Even when] When the model is arranged in a far position in a picture plane and [looks] is rendered smaller, [since] the same model still is used, [a] and the degree of details of the model is not changed. Therefore, the time required for the drawing depends on the degree of [details] detail of the model and the number of models.

However, when the observer pays no attention to [a] the model because the model is [arranged far] minimized and looks smaller on the picture plane or the model is out of a target point of the picture plane, it is not always necessary to draw by using the model having [the same details] a high degree of detail. That is, by using a similar model in which a degree of [details is deteriorated] detail is decreased to a certain extent by using a method of reducing the number of vertices of the model, reducing the number of planes of a polygon, or the like, it. can [be seen] appear as if the same model is used. Fig. 15 shows such an example. When the model is [arranged far] to appear at a distance and its size on the picture plane is small, as shown in the example, it is sufficient to draw the CG by using [a model] models in which data is reduced to, for example, 50% [and] or 25% [for] from that of the original model and [a] for which the degree of [details] detail is reduced [and which was approximated]. By using [the] a model having a data amount smaller than that of the original model as mentioned above, a high drawing speed can be realized.

Such an approximation of the model is useful for the drawing of the CG [model] display as mentioned above. However, if the data amount of the model is simply reduced [when] by approximating [by reducing the degree of] the details of the model, the observer feels

incongruity when he sees the approximated model. [When the] If this sense of incongruity can be suppressed, requests for both of the drawing speed and the drawing quality can be satisfied. For this purpose, it is desirable to reduce the data amount in a manner such that a general characteristic portion of the model is left and the other portions are reduced. Hitherto, such an approximation of the model is often executed by [a] the manual work of a designer, so that much [troublesomeness] expense and time are necessary for the above work.

A method of obtaining a more real image by adhering a two-dimensional image to a plane of a model as a drawing target is generally used. This is called a texture mapping. The image which is adhered in this instance is called a texture. When the approximation of the shape as mentioned above is executed to the model which was subjected to the texture mapping, it is necessary to also pay attention to the texture adhered to the model plane. That is, it is necessary to prevent a deterioration [of the looking] in the appearance of the model due to a deformation of the texture shape at the time of approximation and to prevent the occurrence of a [trouble] problem such that [a whole work amount] the amount of work is increased since the texture [is] must be again adhered to the approximated model.

In [the] past studies, according to Francis J. M. Schmitt, Brian A. Barsky, and Wen-Hui Du, "An Adaptive Subdivision Method for Surface-Fitting from Sampled Data", Computer Graphics, Vol. 20, No. 4, August, 1986, although the shape is approximated by adhering the Bezier patch to a three-dimensional shape, there is a problem <u>in</u> that a general polygon is not a target.

According to Greg Turk, "Re-Tiling Polygonal Surface", Computer Graphics, Vol. 26, No. 2, July, 1992, a trial of hierarchically approximating a polygon model is executed. There is, however, a problem [such] <u>in</u> that A.1though the algorithm in the above paper can be applied to a round shape, it is not suitable [to] <u>for</u> a square shape and a general shape is not a target. Further, it is not considered to approximate the shape on the basis of characteristic points of the object shape.

Further, according to Hugues Hoppe et al., "Mesh Optimization", Computer Graphics Proceedings, Annual Conference Series, SIGGRAPH 1993, a model is approximated in a manner such that an energy is introduced to an evaluation of the approximated model, and operations for removing the edge, dividing the patch, and swapping the edge are repeated so as to minimize the energy. According to the method of the paper, however, it is necessary to execute a long

repetitive calculation until the minimum point of the energy is found out. In addition, a solving method such as a simulated annealing or the like is necessary in a manner similar to other energy minimizing problems so as not to reach a local minimum point. There is no guarantee that the energy minimum point is always visually the best point.

Further, in those papers, no consideration is made up to the texture adhered to the model upon approximation. Consequently, the method of approximating the model according to the methods in the papers has a problem [such] in that double processes are required in which the texture is newly adhered to the approximated model after the approximation.

As mentioned above, the past studies have problems regarding the approximation of a model when a polygon is drawn. That is, the conventional method has problems such that application of the shape approximation is limited, a long calculation time is necessary for approximation, and the approximation in which generally-needed characteristic points are considered is not executed. The approximation of figure data to realize a switching of continuous layers, in which the sense of incongruity to be given to the observer at the time of the switching of the approximated model is considered, is not executed.

When the approximation is executed to the geometric model to which the texture is adhered, there is a problem [such] in that a measure to prevent a quality deterioration after the approximation, by keeping the shape of the texture adhered to the model, is not taken. There is also a problem [such] in that a measure to eliminate [a] the necessity to newly adhere the texture after the approximation is not taken. Further, there is a problem that the approximation in which the existence of the texture itself is considered is not executed.

OBJECTS AND SUMMARY OF THE INVENTION

It is, therefore, an object of the invention to provide a method and apparatus for hierarchically approximating figure data with an image in the drawing of CG [as if the] so that high speed drawing is performed while maintaining a quality of the drawing.

It is another object of the invention to provide a method and apparatus for hierarchically approximating figure data with an image as if the approximation of a geometric model is performed in consideration of the existence of a texture itself.

According to the invention, in order to solve the above problems, there is provided a hierarchical approximating method of shape data for approximating shape data to data of a desired resolution, comprising the steps of: evaluating an importance of each of the

edges which construct the shape data; removing an unnecessary edge on the basis of a result of the edge evaluation; and determining a vertex position after the unnecessary edge was removed.

According to the invention, in order to solve the above problems, there is provided a hierarchical approximating method of shape data with an image for approximating shape data to which image data was adhered to data of a desired resolution, comprising the steps of: determining which edge in the shape data should be removed upon approximation; determining a new vertex position in the shape data after the edge removal performed on the basis of the edge removal determination; and removing an unnecessary vertex in the image data adhered to the shape data in accordance with outputs from the edge removal determining step and the vertex movement determining step and moving a vertex on the image data in accordance with the new vertex position in the shape data.

According to the invention, in order to solve the above problems, there is provided an approximating apparatus [of] <u>for</u> figure data for approximating shape data to-that of a desired resolution, comprising: evaluating means for evaluating an importance of each of <u>the</u> edges which construct the shape data; edge removing means for removing an unnecessary edge on the basis of a result of the edge evaluation; and vertex

position determining means for determining a vertex position after the unnecessary edge was removed.

According to the invention, in order to solve the above problems, there is provided a hierarchical approximating apparatus [of] for figure data with image data for approximating shape data to which image data is adhered to data of a desired resolution, comprising: edge removal determining means for determining which edge in the shape data is removed upon approximation; vertex movement determining means for determining a new vertex position in the shape data after the edge removal; and image data removal and movement determining means for removing an unnecessary vertex in the image data adhered to the shape data in accordance with outputs from the edge removal determining means and the vertex movement determining means and for moving the vertex on the image data in accordance with the new vertex position in the shape data.

According to the invention as mentioned above, the importance of each of the edges of the shape data is evaluated, the unnecessary edge is removed on the basis of the evaluation, a new vertex after the edge removal is determined, and further, the vertex is moved on the image data in accordance with the new vertex position. Thus, the shape data can be approximated so that the change in shape is little

while suppressing the deterioration of the image data adhered to the shape model.

The above and other objects and features of the present invention will become apparent from the following detailed description and the appended claims with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flowchart of a hierarchical approximation of a texture mapped polygon model according to the invention;

Fig. 2 is a diagram showing an example of a drawing apparatus which can be adhered to the invention;

Figs. 3A and 3B are schematic diagrams for explaining equation (1);

Figs. 4A and 4B are schematic diagrams showing an example of a vertex position decision;

Figs. 5A and 5B are schematic diagrams showing an example of a method of determining a position at which a vertex to be left is put;

Figs. 6A and 6B are diagrams schematically showing an example in which a texture is allocated on a certain plane of a polygon model;

Figs. 7A and 7B are diagrams schematically showing an integration of vertices and texture coordinates in association with an edge removal;

Figs. 8A to 8C are diagrams for explaining that the texture is changed by the integration of the vertices;

Figs. 9A to 9D are diagrams for explaining a case where two different textures are adhered to one polygon;

Fig. 10 is a schematic diagram for explaining an equation (2);

Figs. 11A to 11C are schematic diagrams showing examples of a method of forming an approximate model of a middle layer;

Fig. 12 is a diagram schematically showing an example of a processing result according to an embodiment of the invention;

Fig. 13 is a diagram schematically showing an example of a processing result according to an embodiment of the invention;

Fig. 14 is a schematic diagram showing an example of a CG drawing according to a conventional method; and

Fig. 15 is a schematic diagram showing an example of a desirable CG drawing.

<u>DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS</u>

An embodiment of the invention will now be described hereinbelow with reference to the drawings. Fig. 1 is a flowchart for a hierarchical approximation of a geometric (polygon) model which was subjected to a

texture mapping according to the invention. Fig. 2 shows an example of a structure of a drawing apparatus which can execute the processes of the flowchart.

As shown in Fig. 2, the drawing apparatus can be constructed by a computer with a standard structure which comprises: a keyboard 1; a data input device such as floppy disk drive (FDD) 2, magnetooptic disk (MO) drive 3, or the like; a data processing apparatus constructed by a CPU 4, an RAM 5, and the like; an external memory apparatus such as hard disk 6, semiconductor memory 7, or the like; and a display apparatus 8 such as a CRT or the like, and in which those component elements are respectively connected by a bus 9. As an input device, a mouse or the like [is] may also be used. The floppy disk drive 2 and MO drive 3 are also used as data output devices. Further, data can be also supplied from a network such as [an] the internet. The above structure is an example and the actual drawing apparatus can have various constructions.

First, processes in the flowchart shown in Fig. 1 will be schematically described. A texture as image data is allocated and adhered to each plane of a polygon. In the invention, in order to approximate the polygon, edges constructing the polygon are removed and the shape is approximated. Since the shape of the polygon is merely approximated by only removing the

edges, in order to approximate the textures allocated to the planes of the polygon, an optimization is executed by integrating the textures associated with the edge removal and moving the coordinates of the textures.

In the first step S1, original polygon data is inputted. The texture is adhered to each plane for the inputted polygon data. The input of the data and the adhesion of the texture are manually performed from the keyboard 1 or by a method whereby data which has been made in another place and stored in a floppy disk or an MO disk is read out by the FDD 2 or MO drive 3. The polygon data can be also inputted through a network such as [an] the internet.

In step S2, each-edge of the inputted polygon data is evaluated for performing the edge removal. In the edge evaluation in step S2, each edge of the inputted polygon data is converted into a numerical value by a method, which will be described [hereinlater] below, and is set to an evaluation value. In step S3, the e~7aluation values of the edges obtained in step S2 are sorted and the edge having the minimum evaluation value is-selected. The processing routine advances to step S4. In step S4, the edge having the minimum evaluation value which was selected in step S3 is removed.

When the edge is removed in step S4, the processing routine advances to step S5. In step S5, the position of the vertex which remains after the edge was removed in step S4 is determined. In step S6, the texture portion which becomes unnecessary in association with the edge removal is removed and the positions of the remaining texture coordinates are determined.

[The approximated] Approximated polygon data which was approximated at a precision of one stage and was subjected to the texture mapping is obtained by the foregoing processes in steps S2 to S6. The edge removal, the determination of a new vertex, and the process of the texture in association with them are repeated by repeatedly executing the processes in steps S2 to S6. Consequently, the approximated polygon data, which was subjected to the texture mapping can be obtained at a desired precision.

When the approximated polygon data which was subjected to the texture mapping at a desired precision in step S6 is obtained (step S7), the processing routine advances to step S8. The obtained approximated polygon data which was texture mapped is drawn on the display apparatus 8. The obtained approximated polygon data which was texture mapped can be also stored into an external memory apparatus such as a hard disk 6 or memory 7, a floppy disk inserted in the FDD 2, or an MO

inserted in the MO drive 3. The derived data can be also supplied and stored to another computer system through the network.

The processes in the above flowchart are executed mainly by the CPU 4 in the hardware structure of Fig. 2. Instructions or the like which are necessary during the processes are sent from the input such as a keyboard 1 or the like to the CPU 4.

Processes regarding a model approximation will now be described. As mentioned above, the approximation of the polygon model is executed by repeating the edge removal. In this instance, small convex and concave components which do not contribute to [a] the general shape of the model are judged and edges which should be preferentially removed are determined on the basis of the judgement result. In order to select the edges which are preferentially removed, [how] the extent to which the edges constructing the model contribute to the general shape, namely, the importance of [the] each edge is evaluated and the removal is executed [from] to remove the edge [of a small] with the smallest evaluation value. In step S2, the importance of [the] each edge is evaluated.

In order to select the edge which is suitable to be removed by obtaining the evaluation value, an evaluation function to evaluate [how] the extent to

which each of the edges constructing the polygon model contributes to the shape of the polygon model is introduced. The following equation (1) shows an example of the evaluation function. Figs. 3A and 3B are diagrams for explaining the equation (1).

[Equation 1]

$$F(e) = \sum_{i} |aV_i + bS_i| \qquad \ldots(1)$$

where

$$V_i = (N_i \cdot E) \times A_i$$

$$S_i = |E| \times A_i$$

Fig. 3B shows an example in which a part of a spherical polygon model shown in Fig. 3A in which each plane is [constructed] bounded by a triangle is enlarged. By the equation (1), an edge e constructed by two vertices v_1 and v_2 is evaluated. With respect to the vertices v_1 and v_2 [constructing] bounding the edge e (v_1, v_2), when sets of planes including them as vertices assume $S(v_1)$ and $S(v_2)$, a range of i is set to $S(v_1) \cup S(v_2)$. That is, $1 \le i \le 10$ in the example shown in Fig. 3B. In the diagram, E denotes a vector having the direction and length of the edge e; N_i denotes a unit normal vector of each plane; A_i an area of the plane; and $|E|$ a length of the vector E.

The equation (1) is constructed by two terms. The first term V_i shows a volume amount which is

changed when the edge as an evaluation target is removed. The volume amount here denotes a virtual volume of a shape specified by the shape data of the polygon. The second term S_i shows a value obtained by multiplying the planes existing on both sides of the target edge with the length of the target edge. It denotes a change amount of the volume of the plane including only the target edge. Coefficients a and b are multiplied to the two terms. The user can select which one of the first term V_i and the second term S_i is preferentially used by properly setting the values of the coefficients.

The first term V_i largely depends on the peripheral shape of the edge as an evaluation target. On the other hand, the second term Si depends on the length of the target edge and the area of planes existing on both sides of the target edge. In the case of a polygon model having a flat shape like a sheet of paper, when the edge e (v_1 and v_2) is removed, the change amount by the term S_i is larger than that by the term V_i. In the polygon model constructed by planes in which all of them have similar shapes and areas, for example, in the model shown in Fig. 3A, the change amount by the term V_i is larger than that by the term S_i.

The value of the equation (1) is calculated with respect to each of the edges constructing the

polygon model and the evaluation value for each edge is obtained. In step S3, the calculation values are sorted in accordance with the values and the edge having the minimum evaluation value is selected, thereby obtaining the edge whose contribution to the model shape when the edge is removed is the smallest.

When the importance of the edge is evaluated in step S2, the length of edge is considered. When the evaluation values are the same, the shorter edge can be also set [to] as a target to be removed.

Although the local evaluation value in the polygon model is obtained by the equation (1), each edge can be also evaluated by a value obtained by adding the evaluation values of the peripheral edges to the evaluation value of a certain target edge. In this case, the evaluation can be performed not only with the peripheral shape of one edge but also with the shape or a wide range. When the area which the user wants to evaluate is wide as mentioned above, the calculation range of the equation (1) can be widened in accordance with such a wide area.

In addition to the evaluation value simply derived by the calculation of the equation (1), the user can give the evaluation value or can operate the evaluation value. Therefore, when there is a portion which the user wants to leave [in the shape] intact without approximation or a portion which he,

contrarily, wants to [promptly] approximate, the intention of the designer or operator can be reflected [to] in the approximating process by designating such a portion. In this case, the evaluation value is determined by executing a weighted addition by giving a weight coefficient to each of the value operated by the user and the calculated evaluation value.

In this case, the approximation in which the intention of the designer is reflected [stronger] can be performed [depending on a way of] by giving a weight coefficient, for example, by giving a large weight to the evaluation value designated by the user. On the contrary, when a large weight is given to the evaluation value obtained by the calculation of the equation (1), an accurate approximation can be performed by a quantitative evaluation of the volume change in shape. In this manner, the change in shape can be freely controlled by the weighting process.

When the evaluation values for the edges of the polygon data are obtained in step S2 as mentioned above, the obtained evaluation values are sorted and the edge having the minimum evaluation value is selected in step S3. When sorting the edges, for example, a quick sorting as a known technique can be used. Other sorting methods can be also obviously used. Since the sorting methods including the quick sorting are described in detail in "Algorithm

Dictionary" published by Kyoritsu Publication Co., Ltd. or the like, the description is omitted here. The selected edge having the mini-mum evaluation value is removed in step S4.

Although the case where the edge having the minimum evaluation value is simply removed has been described here, the removing order of the edges or the edge which is not removed can be also arbitrarily designated. When the edge is not removed, there is no change in Shape of such a portion. For example, in the case where it is desirable that the shape is not changed like a portion in which two models are in contact each other, it is sufficient to set a portion where no edge is removed.

When the edge is removed in step S4, the vertices (v_1 and v_2 in this case) constructing the edge are lost. In step S5, therefore, a new vertex position in association with the edge removal is determined. Figs. 4A and 4B show examples of the vertex position determination. After the edge was removed, either one of the two vertices constructing the edge is left. In this case, the edge e (v_1 and V_2) in a layer N in Fig. 4A is removed, thereby obtaining a layer (N + 1) shown in Fig. 4B. The vertex v_1 remains and becomes a new vertex v'.

In this instance, the shape after the edge removal is changed [in dependence] <u>depends</u> on the

position of the vertex v_1 which remains. Figs. 5A and 5B [shows] <u>show</u> examples of a method of determining the position where the vertex to be left is located. Figs. 5A and 5B show cross sectional views of an edge shape in the polygon data. That is, Fig. 5A shows a case where the edge $e(v_1, v_2,)$ [constructed] <u>bounded</u> by the vertices v_1 and v_2 is formed in a convex shape [for] <u>including</u> the outer edges of v_1 and v_2. Fig. 5B shows a case where the edge $e(v_1, v_2,)$ [which sandwiched from] <u>is between</u> the upper and lower directions [by] <u>of</u> the outer edges of v_1 and v_2 [and is formed in] <u>forming</u> an S shape. In Figs. 5A and 5B, v' indicates a vertex to be left.

In Figs. 5A and 5B, areas S_1 and S_2 shown by hatched regions show volume change amounts when the edge $e(v_1, v_2)$ is removed and the vertex v' is left. The vertex v' which is left after the edge $e(v_1, v_2)$ was removed is positioned where the volume change amount S_1 on the vertex v_1 side and the volume change amount S_2 on the vertex V_2 side are equal. By arranging the vertex to the position where the volume change amounts on both sides of the removed edge $e(v_1, v_2)$ are equal as mentioned above, the shape after the edge removal can be more approximated to the original shape.

Although the vertex v_1 which is left and becomes a new vertex is arranged to the position where the volume change amounts on both sides of the edge are

equal irrespective of the peripheral shape of the edge which is removed in step S5 in the above description, the invention is not limited to the example. For example, the vertex v' can be also arranged at a position where the volume change upon edge removal is the minimum. As mentioned above, the method of arranging the vertex v' to the position where the volume change amounts on both sides of the edge are equalized and the method of arranging the vertex v' to the position where the volume change is the minimum can be selectively used in accordance with a desire of the user.

In consideration of the peripheral shape of the edge, when the shape has a concave or convex shape, the vertex v' can be also arranged at a position where the volume change after the edge removal is the minimum. When the periphery has an S-character shape, the vertex v' can be arranged at a position where the volume change amounts on both sides of the edge are equalized. In this case, the position of the vertex v' is deviated to either one of the ends of the edge in <u>the</u> case of the concave or convex shape. In case of the S-character shape, the vertex v' is arranged in the middle of the S character. Thus, both of an effect to suppress the volume change and an effect to absorb the continuous changes like an S character by the plane can be [derived] <u>achieved</u>.

For example, an area in which a change having a small S-character shape continues like a saw tooth can be approximated by one plane in a general shape. A portion having a large change except the S-character shape can be approximated by a shape which is closer to the original shape. In the approximation in which the shape has a priority, such a setting is also possible. The approximating methods can be selectively used in accordance with the intention of the user.

It is also possible not to change the vertex position remaining after the edge removal from the vertex position before the edge removal. That is, in the example shown in Figs. 4A and 4B , for example, after the edge $e(v_1, v_2)$ was removed, only the vertex v_1 is left as a new vertex v' without changing the position from the position before the removal. This is effective means when it is desirable not to move the position of a target vertex because the target vertex exists at a contact point with the other model or the like.

When the edge is evaluated and removed and the new vertex in association with the edge removal is determined in the steps up to step S5, a process regarding the texture adhered to each plane of the polygon model is executed in step S6. Figs. 6A and 6B schematically show examples in which image data (texture) is allocated to a certain plane on the

polygon model. Fig. 6A shows a polygon model itself comprising vertices V_1 to V_8. It shows that when an edge $e(V_3, V_6)$ shown by a broken line is removed from the model shown in the left diagram, the model is approximated to a shape shown in the right diagram.

Fig. 6B shows a state in which a texture is adhered to the polygon model shown in Fig. 6A. In this instance, for easy understanding, image data based on a portrait is used as a texture. Coordinates vt_1 to vt_8 in Fig. 6B correspond to the vertices v_1 to v_8 in Fig. 6A, respectively. Fig. 6B, therefore, shows that the coordinates vt_1 to vt_8 in the diagram on the left side are changed as shown in a diagram on the right side in association with the removal of the edge $e(V_3, V_6)$ in Fig. 6A.

The vertex V_6 is removed by the approximation of the polygon model and the two vertices v_3 and v_6 in this model are integrated to one vertex V_3. In association with it, by removing the edge $e(v_3, v_6)$ comprising v_3 and v_6, triangular areas on both sides including [such an edge is] the removed edge are lost. In this instance, unless the loss of those triangular areas is considered, the image data comprising the texture coordinates Vt_3, Vt_4, and Vt_6 and the image data comprising Vt_3, vt_5, and Vt_6 are lost.

As shown by the texture in the diagram on the right side in Fig. 6B, therefore, it is necessary to execute an integration and a position movement to the texture in accordance with the approximation of the edge removal. Thus, the continuous image data on the approximated model surface can be reproduced.

In this example, the vertices v_3 and v_6 are integrated on the polygon model and the vertex v_3 remains. The remaining vertex V_3 is set to a vertex V_3'. The position of the vertex V_3' is arranged at a predetermined distribution ratio t on the coordinates between the edge $e(v_3, v_6)$ comprising V_3 and v_6 before approximation. In this case, the coordinates of the vertex v_3' can be calculated by $[(1 - t) \times V_3 + t \times V_6]$. When $0 \leq t \leq 1$, the distribution coefficient t exists on the edge straight line of the edge $e(v_3, v_6)$ before approximation and, when $t < 0$ or $1 < t$, t exists out of the edge $e(v_3 , v_6)$. By changing a value of t, therefore, a shape change amount after the model was approximated by the edge removal can be controlled.

As mentioned above, the vertices v_3 and v_6 are integrated on the polygon model and are set to the vertices v_3' and V_3' is arranged between the vertex v_3 and the vertex v_6. The texture coordinates vt_3 and vt_6 corresponding to those two vertices are, therefore, also integrated to the coordinates Vt_3 after approximation and are set to coordinates vt_3'. The

coordinates vt_3' are arranged between the coordinates Vt_3 and vt_6 before approximation.

Figs. 7A and 7B schematically show the integration of vertices and the integration of texture coordinates in association with the edge removal. Fig. 7A shows an example in which the integrated vertex V_3' is arranged to the position calculated by $[(1 - t) \times v_3 + t \times v_6]$ in association with the removal of the edge $e(v_3, v_6)$. A distribution of the remaining texture coordinates can be obtained in a manner similar to the arrangement of the vertex v_3' based on the distribution t. That is, as shown in Fig. 7B, as for the distribution of the remaining texture coordinates Vt_3', by calculating $[(1 - t) \times Vt_3 + t \times Vt_6]$ in a manner similar to the distribution t between the above vertices v_3 and v_6, an image can be distributed in a form according to a change in model shape to which the image is adhered. Thus, as shown in the diagram on the right side of Fig. 6B, the textures can be continuously adhered to the polygon model.

In this instance, when the position of the coordinates Vt3 Of the texture data corresponding to the vertex V_3 on the polygon model is not changed in accordance with the change in model shape as mentioned above, for example, in the texture shown in Fig. 6B, an image existing at the position of the face

corresponding to the triangular plane including the removed edge $e(V_3, V_6)$ cannot be adhered to the model.

With respect to an original polygon model shown in Fig. 8A, for example, when the coordinates vt_6 on the texture allocated to the vertex v_6 are made correspond to the remaining vertex V_3 side from the integration relations of vertices after the removal of the edge e without considering the image data allocated to the triangular plane which disappears at the time of the removal of the edge $e(V_3, V_6)$, the portion of the face disappears as shown in Fig. 8B. Further, when the coordinates of Vt_3 before the edge removal are succeeded as they are after the edge removal without considering the integration relation of the vertices at the time of the removal of the edge e, as shown in Fig. 8C, since the coordinates of the vertex v_3 change after the removal of the edge e and an area of each plane changes, the resultant image to which the texture was adhered is distorted. That is, the texture data also needs to be changed in accordance with the change in plane and change in model vertex position due to the edge removal.

When the texture is adhered to the polygon model, there is a case where not only one texture but also a plurality of different textures are allocated to the model. In this case, a boundary in which the

texture is switched from a certain texture to another texture exists.

In case of adhering the texture to the polygon model, as mentioned above, the texture is allocated to each vertex of the model. Even in the boundary of the texture, therefore, the boundary is allocated to each vertex constructing the edge of the model. Further, as mentioned above, the approximation of the model is performed by repeating the edge removal only a desired number of times. In this instance, if the texture area allocated to the edge as a target of the removal is in the texture, as shown in Figs. 6 and 7 mentioned above, the model can be approximated while holding a continuity of the image.

However, when the area of the image allocated to the edge as a removal target exists just on the boundary of the image, the polygon model is approximated by the edge removal and since the vertex position is moved, a plurality of textures are mixed and the [shape of] appearance of the texture is broken. To prevent [it] this, it is necessary to make a discrimination so as not to break the image boundary at the time of the edge removal and to decide sizes of a change of the outline portion by the edge removal.

As shown in Fig. 9A, two different textures [of a texture] comprising [the] an image of [the] a hatched portion and [a texture comprising the] an image

of [the] a face [portion mixedly exist and] are both adhered to one polygon model. Fig. 9B shows a certain continuous edge train in the model shown in Fig. 9A. In the model shown in Figs. 9A and 9B, for example, when the edge $e(v_4, v_5)$ comprising the vertices v_4 and v_5 is removed and the vertex v_4 is left after the removal, when executing a process to arrange a vertex v_4' based on the vertex v_4 to the middle position of the edge $e(v_4, v_5)$ as a removal target, an outline portion of the edge changes as shown in Fig. 9C.

In this case, since the outline portion of the face image has also been adhered to each of the vertices v_3 to v_6, as shown in Fig. 9D, the shapes of the two adhered images are broken. In this example, the shape of the lower portion of the face picture is largely changed and the image of the hatched region increases. As mentioned above, in the edges of the model to which the outline portion of the image is allocated, if the edge removal is simply repeated as mentioned above, the quality after the approximation is deteriorated.

To prevent [it] this, a removal evaluating function of the edge as a boundary portion of the texture is introduced and when the shape of the texture boundary is largely changed by the edge removal, it is necessary to use any one of the following methods. Namely, as a first method, the relevant edge is not

removed. As a second method, although the edge is removed, a movement amount of the vertex position after the removal is adjusted. The following equation (2) is used as a removal evaluating function of each edge in this instance. Fig. 10 shows a diagram for explaining the equation (2).

$$F(e) = \sum_i \left|(N_i \cdot E) \times L_i\right| \qquad \ldots(2)$$

In the equation (2), E denotes the vector having the direction and length of the edge e, Ni indicates the normal vector of the edge, and Li the length of edge. A range of i corresponds to the whole edge of the boundary lines existing before and after the edge as a removal target. The equation (2) denotes an area change amount when the edge of the boundary portion is removed. Therefore, when the calculation value of the equation (2) is large, a change of the outline portion by the edge removal is large.

Namely, when the calculation value of the equation (2) is large, the area change in the outline portion of the texture increases, so that there is a fear of occurrence of the breakage of the texture shape. To prevent [it] <u>this</u>, there is a method whereby the relevant edge is not removed like the foregoing first method. However, like the foregoing second

method, there is also a method whereby the texture coordinates after the edge removal are moved within a range where the value of the equation (2) is smaller than the designated value, thereby consequently decreasing the change amount of the outline portion. By using the second method, the breakage of the texture after the approximation can be suppressed.

As mentioned above, the approximated polygon model to which the texture having a desired precision is adhered can be obtained. In this case, when the texture is adhered to the original model, there is no need to again adhere the texture to the model after completion of the approximation and the approximated model with the texture can be automatically obtained.

As mentioned above, the approximated model obtained by repeating the processes in steps S2 to S6 is stored [into] in the external storing apparatus such as hard disk 6 or memory 7. However, when displaying in step S8, the approximated model stored in the external storing apparatus is read out, drawn, and displayed to the display apparatus 8. As already described in the foregoing prior art, in this display, for example, when the model is displayed as a small image on the picture plane because it [is arranged] appears at a remote location or when the observer doesn't pay attention to the model because it is out of the target point on the picture plane, the model is

switched to the model of a layer that was more approximated and the image is displayed.

Upon switching [of] to the approximated model, if the model is suddenly switched to the model in which a degree of approximation largely differs, a sudden change occurs in the shape of the displayed model at a moment of the switching and a feeling of disorder is given to the observer.

To prevent that [the] feeling of disorder [is given], it is sufficient that a number of models whose approximation degrees are slightly changed are prepared and stored into the external storing apparatus and the display is performed while sequentially switching those models. In this case, however, since an amount of models to be stored increases, it is [no] not efficient. Therefore, to realize a smooth continuous conversion even [in the] with a small number of models, it is sufficient to interpolate the model among the discrete layers and to obtain the model of the middle layer.

For example, in the example shown in Figs. 4A and 4B mentioned above, the vertex after the edge $e(v_1, v_2)$ was removed is set to v'. However, as for the vertex v', it is considered that the vertices v_1 and v_2 in the edge $e(v_1, v_2)$ approach each other and become the vertex v'. Namely, the vertices v_1 and v_2 are consequently integrated to the vertex v'. As mentioned

above, since the correspondence relation of the vertices before and after the edge removal is known, the data between the data before and after the edge removal can be obtained by an interpolation from the data before and after the edge removal by using the correspondence relation of the vertices.

Such a forming method of the approximated model in the middle layer between the discrete layers has already been described in detail in Japanese Patent Application No. 6-248602 regarding the proposition of the present inventors.

Figs. 11A to 11C show the formation of the approximated model of the middle layer using the correspondence relation of the vertices between two layers as mentioned above. In Figs. 11A to 11C, a layer before the edge removal is set to a layer N as shown in Fig. 11A and a layer after the edge removal is set to a layer N+1 as shown in Fig. 11C, thereby obtaining a model of a middle layer N' shown in Fig. 6B from those two layers.

In the example, the vertices v_1, and v_2 [constructing] <u>bounding</u> the edge $e(v_1, v_2)$ of the layer N are integrated to v_1 in the layer N+1 and the deleted vertex v_2 is integrated to v_1. From the correspondence relation of the vertices, in the middle layer N', the positions of vertices v_1' and V_2' [constructing] <u>bounding</u> an edge $e'(v_1', V_2')$ corresponding to the edge

$e(v_1, v_2)$ of the layer N can be obtained by the linear interpolation between the layers N and N+1. Although the example in which one middle layer is obtained is shown here, a degree of linear interpolation is changed in accordance with a desired number of middle layers and a plurality of middle layers can be obtained. The formation of the approximated model of the middle layer can be performed in a real-time manner in accordance with a situation in which the model is displayed.

Although the case where the approximated model of the middle layer is formed and displayed in a real-time manner while displaying the model has been described here, the invention is not limited to such an example. For instance, it is also possible to [construct] <u>practice the invention</u> in a manner such that the approximated model of the middle layer is previously formed and stored in the external storing apparatus and the stored approximated model of the middle layer is read out at the time of the display.

Although the case where one edge is removed has been mentioned as an example here, since the edge removal is repeated a plurality of number of times in the approximation of the actual model, one vertex of a certain layer corresponds to a plurality of vertices of another layer which is closer to the original model. By using the correspondence relation of the vertices in those two layers as mentioned above, the vertices of

the model can be made to correspond among all of the layers. The model of the middle layer is obtained on the basis of the correspondence relation of the vertices derived as mentioned above.

As mentioned above, since the coordinates of the image data in the texture are allocated to each vertex of each model, in a manner similar to the case of the vertices of such a model, the model to which the texture was adhered in the middle layer can be obtained by the interpolation of the texture coordinates vt_1 and vt_2 allocated to the vertices v_1 and v_2, respectively. By such a process, the models in a range from the original model to the most approximated model can be smoothly continuously obtained.

By the above processes, the discrete hierarchical approximated model can be obtained and the model of the middle layer can be also obtained. The approximated model obtained and stored as mentioned above is switched in accordance with the size, position, speed, and attention point of the viewer of the apparent model on the picture plane in the display apparatus 8 and is displayed in step S8. Figs. 7A and 7B show examples of the approximated model derived by the embodiment.

Fig. 12 schematically shows an example of the processing results according to the embodiment. In this example, the original model is a sphere comprising

182 vertices, 360 planes, and 279 texture coordinates. An image of the earth is adhered as a texture to the sphere. It is approximated for the original model by reducing every 60% in comparison of the number of vertices. Fig. 13 shows a wire frame state of a model when the texture of the same approximated model is not adhered. In Fig. 12, since the image is consistently held, it is difficult to know a degree of approximation, in the approximated state before the texture image is adhered as shown in Fig. 13, the progress of the approximation can be clearly seen.

As more specifically shown in Fig. 13, by using the present invention, even if the number of vertices is reduced to 36% or 21.6% of the original model, the hierarchical approximated model can be obtained without losing the general shape which the original model has.

Although the case where the texture image is adhered to the polygon model has been described above, the invention can be also obviously applied to the case where the texture image is not adhered. In this case, step S6 can be omitted in the flowchart shown in Fig. 1 mentioned above.

As described above, according to the invention, when image data (texture) is adhered to geometric data such as polygon data which is used in the CG, the model can be approximated to a desired

degree of details while preventing the breakage of the texture shape or [a] an apparent deterioration of the quality. [A troublesomeness such that after the model was approximated, the texture is newly adhered can be also omitted.]

According to the invention, therefore, there is an effect such that the geometric model which is used in the CG can be approximated in a state in which the texture is adhered. There is also an effect such that not only is the model [is merely] approximated but also the breakage of the [shape] appearance of the texture in the approximation result can be suppressed.

By using the geometric model approximated by the method based on the invention, in the drawing of the CG, there is an effect such that a request for drawing of at a high speed and at a high picture quality can both be satisfied.

Further, according to the invention, an importance degree of each edge constructing the geometric model which is used for the CG can be evaluated by an evaluation value. There is an effect such that the geometric model can be approximated by preferentially removing the edge of a low evaluation value of the edge.

According to the invention, the position of the vertex remaining after the edge was removed can be determined so as to suppress a change in general shape.

Thus, there is an effect such that a feeling of disorder upon looking when drawing by using the approximated model can be suppressed.

According to the invention, figure data which is used in the CG can be approximated by a plurality of resolutions. There is an effect such that by using the figure data derived by the invention, both of the <u>goals of</u> drawing at a high speed and [the] drawing with a high quality can be satisfied.

The present invention is not limited to the foregoing embodiments but many modifications and variations are possible within the spirit and scope of the appended claims of the invention.

ABSTRACT OF THE DISCLOSURE

[Polygon data inputted in the] Polygonal data input in a first step is subjected to evaluation [of] in which all edges of the polygon data are ranked in importance on the basis of a volume change [due to an edge removal by a predetermined evaluating function in the second step] caused by removal of that edge. The edges are sorted on the basis of an evaluation value in [the] a third step. In [the] a fourth step, the edge of a small evaluation value is determined to be an edge of a small influence on [a] the general shape and is removed. In [the] a fifth step, a new vertex is determined from the loss of vertex by the edge removal. In [the] a sixth step, a movement of texture coordinates and a removal of the texture after the edge removal are executed on the basis of the area change of the texture due to the edge removal by a predetermined evaluating function. In [the] a seventh step, by repeating the processes in the second to sixth steps, a polygon model approximated to a desired layer can be obtained.

S96P1067

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application for Letters Patent

Title : COMPUTER ANIMATION GENERATOR

Inventor(s): Junji HORIKAWA

Takashi TOTSUKA

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to method and apparatus for hierarchically approximating shape data with an image, in which a data amount is reduced by reducing a complexity of a shape of a geometric model which is used in CG (Computer Graphics), thereby enabling the CG to be drawn at a high speed. The invention also relates to method and apparatus for hierarchically approximating shape data with an image, which is suitable for use in a game using CG, VR (Virtual Reality), designing, and the like since a shape which was approximated so as not to give a sense of incongruity is changed.

Description of the Prior Art

When drawing using a model by the CG, the same model is generally always used. For example, as shown in Fig. 14, a detailed original model having data of 100% is formed and the CG is drawn on a display by using it. Even when the model is arranged in a far position in a picture plane and looks smaller, since the same model is used, a degree of details of the model is not changed. Therefore, the time required for the drawing depends on the degree of details of the model and the number of models.

However, when the observer pays no attention to a model because the model is arranged far and looks

smaller on the picture plane or the model is out of a target point of the picture plane, it is not always necessary to draw by using the model having the same details. That is, by using a similar model in which a degree of details is deteriorated to a certain extent by using a method of reducing the number of vertices of the model, reducing the number of planes of a polygon, or the like, it can be seen as if the same model is used. Fig. 15 shows such an example. When the model is arranged far and its size on the picture plane is small, as shown in the example, it is sufficient to draw the CG by using a model in which data is reduced to, for example, 50% and 25% for the original model and a degree of details is reduced and which was approximated. By using the model having a data amount smaller than that of the original model as mentioned above, a high drawing speed can be realized.

Such an approximation of the model is useful for the drawing of the CG model as mentioned above. However, if the data amount of the model is simply reduced when approximating by reducing the degree of the details of the model, the observer feels incongruity when he sees the approximated model. When the sense of incongruity can be suppressed, requests for both of the drawing speed and the drawing quality can be satisfied. For this purpose, it is desirable to reduce the data amount in a manner such that a general

characteristic portion of the model is left and the other portions are reduced. Hitherto, such an approximation of the model is often executed by a manual work of a designer, so that much troublesomeness and time are necessary for the above work.

A method of obtaining a more real image by adhering a two-dimensional image to a plane of a model as a drawing target is generally used. This is called a texture mapping. The image which is adhered in this instance is called a texture. When the approximation of the shape as mentioned above is executed to the model which was subjected to the texture mapping, it is necessary to also pay attention to the texture adhered to the model plane. That is, it is necessary to prevent a deterioration of the looking of the model due to a deformation of the texture shape at the time of approximation and to prevent the occurrence of a trouble such that a whole work amount is increased since the texture is again adhered to the approximated model.

In the past studies, according to Francis J. M. Schmitt, Brian A. Barsky, and Wen-Hui Du, "An Adaptive Subdivision Method for Surface-Fitting from Sampled Data", Computer Graphics, Vol. 20, No. 4, August, 1986, although the shape is approximated by adhering the Bezier patch to a three-dimensional shape, there is a problem that a general polygon is not a

target.

According to Greg Turk, "Re-Tiling Polygonal Surface", Computer Graphics, Vol. 26, No. 2, July, 1992, a trial of hierarchically approximating a polygon model is executed. There is, however, a problem such that although the algorithm in the above paper can be applied to a round shape, it is not suitable to a square shape and a general shape is not a target. Further, it is not considered to approximate the shape on the basis of characteristic points of the object shape.

Further, according to Hugues Hoppe et al., "Mesh Optimization", Computer Graphics Proceedings, Annual Conference Series, SIGGRAPH 1993, a model is approximated in a manner such that an energy is introduced to an evaluation of the approximated model, and operations for removing the edge, dividing the patch, and swapping the edge are repeated so as to minimize the energy. According to the method of the paper, however, it is necessary to execute a long repetitive calculation until the minimum point of the energy is found out. In addition, a solving method such as a simulated annealing or the like is necessary in a manner similar to other energy minimizing problems so as not to reach a local minimum point. There is no guarantee that the energy minimum point is always visually the best point.

Further, in those papers, no consideration is made up to the texture adhered to the model upon approximation. Consequently, the method of approximating the model according to the methods in the papers has a problem such that double processes in which the texture is newly adhered to the approximated model after the approximation.

As mentioned above, the past studies have problems regarding the approximation of model when a polygon is drawn. That is, the conventional method has problems such that application of the shape approximation is limited, a long calculation time is necessary for approximation, and the approximation in which generally-needed characteristic points are considered is not executed. The approximation of figure data to realize a switching of continuous layers, in which the sense of incongruity to be given to the observer at the time of the switching of the approximated model is considered, is not executed.

When the approximation is executed to the geometric model to which the texture is adhered, there is a problem such that a measure to prevent a quality deterioration after the approximation by keeping the shape of the texture adhered to the model is not taken. There is also a problem such that a measure to eliminate a necessity to newly adhere the texture after the approximation is not taken. Further, there is a

problem that the approximation in which the existence of the texture itself is considered is not executed.

OBJECTS AND SUMMARY OF THE INVENTION

It is, therefore, an object of the invention to provide method and apparatus for hierarchically approximating figure data with an image in the drawing of CG as if the high speed drawing is performed while maintaining a quality of the drawing.

It is another object of the invention to provide method and apparatus for hierarchically approximating figure data with an image as if the approximation of a geometric model is performed in consideration of the existence of a texture itself.

According to the invention, in order to solve the above problems, there is provided a hierarchical approximating method of shape data for approximating shape data to data of a desired resolution, comprising the steps of: evaluating an importance of each of edges which construct the shape data; removing an unnecessary edge on the basis of a result of the edge evaluation; and determining a vertex position after the unnecessary edge was removed.

According to the invention, in order to solve the above problems, there is provided a hierarchical approximating method of shape data with an image for approximating shape data to which image data was adhered to data of a desired resolution, comprising the

steps of: determining which edge in the shape data should be removed upon approximation; determining a new vertex position in the shape data after the edge removal performed on the basis of the edge removal determination; and removing an unnecessary vertex in the image data adhered to the shape data in accordance with outputs from the edge removal determining step and the vertex movement determining step and moving a vertex on the image data in accordance with the new vertex position in the shape data.

According to the invention, in order to solve the above problems, there is provided an approximating apparatus of figure data for approximating shape data to that of a desired resolution, comprising: evaluating means for evaluating an importance of each of edges which construct the shape data; edge removing means for removing an unnecessary edge on the basis of a result of the edge evaluation; and vertex position determining means for determining a vertex position after the unnecessary edge was removed.

According to the invention, in order to solve the above problems, there is provided a hierarchical approximating apparatus of figure data with image data for approximating shape data to which image data is adhered to data of a desired resolution, comprising: edge removal determining means for determining which edge in the shape data is removed upon approximation;

vertex movement determining means for determining a new vertex position in the shape data after the edge removal; and image data removal and movement determining means for removing an unnecessary vertex in the image data adhered to the shape data in accordance with outputs from the edge removal determining means and the vertex movement determining means and for moving the vertex on the image data in accordance with the new vertex position in the shape data.

According to the invention as mentioned above, the importance of each of the edges of the shape data is evaluated, the unnecessary edge is removed on the basis of the evaluation, a new vertex after the edge removal is determined, and further, the vertex is moved on the image data in accordance with the new vertex position. Thus, the shape data can be approximated so that the change in shape is little while suppressing the deterioration of the image data adhered to the shape model.

The above and other objects and features of the present invention will become apparent from the following detailed description and the appended claims with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flowchart of a hierarchical approximation of a texture mapped polygon model

according to the invention;

Fig. 2 is a diagram showing an example of a drawing apparatus which can be adhered to the invention;

Figs. 3A and 3B are schematic diagrams for explaining equation (1);

Figs. 4A and 4B are schematic diagrams showing an example of a vertex position decision;

Figs. 5A and 5B are schematic diagrams showing an example of a method of determining a position at which a vertex to be left is put;

Figs. 6A and 6B are diagrams schematically showing an example in which a texture is allocated on a certain plane of a polygon model;

Figs. 7A and 7B are diagrams schematically showing an integration of vertices and texture coordinates in association with an edge removal;

Figs. 8A to 8C are diagrams for explaining that the texture is changed by the integration of the vertices;

Figs. 9A to 9D are diagrams for explaining a case where two different textures are adhered to one polygon;

Fig. 10 is a schematic diagram for explaining an equation (2);

Figs. 11A to 11C are schematic diagrams showing examples of a method of forming an approximate

model of a middle layer;

Fig. 12 is a diagram schematically showing an example of a processing result according to an embodiment of the invention;

Fig. 13 is a diagram schematically showing an example of a processing result according to an embodiment of the invention;

Fig. 14 is a schematic diagram showing an example of a CG drawing according to a conventional method; and

Fig. 15 is a schematic diagram showing an example of a desirable CG drawing.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An embodiment of the invention will now be described hereinbelow with reference to the drawings. Fig. 1 is a flowchart for a hierarchical approximation of a geometric (polygon) model which was subjected to a texture mapping according to the invention. Fig. 2 shows an example of a structure of a drawing apparatus which can execute the processes of the flowchart.

As shown in Fig. 2, the drawing apparatus can be constructed by a computer with a standard structure which comprises: a keyboard 1; a data input device such as floppy disk drive (FDD) 2, magnetooptic disk (MO) drive 3, or the like; a data processing apparatus constructed by a CPU 4, an RAM 5, and the like; an

external memory apparatus such as hard disk 6, semiconductor memory 7, or the like; a display apparatus 8 such as a CRT or the like; and the like, and in which those component elements are respectively connected by a bus 9. As an input device, a mouse or the like is also used. The floppy disk drive 2 and MO drive 3 are also used as data output devices. Further, data can be also supplied from a network such as an internet. The above structure is an example and the actual drawing apparatus can have various constructions.

First, processes in the flowchart shown in Fig. 1 will be schematically described. A texture as image data is allocated and adhered to each plane of a polygon. In the invention, in order to approximate the polygon, edges constructing the polygon are removed and the shape is approximated. Since the shape of the polygon is merely approximated by only removing the edges, in order to approximate the textures allocated to the planes of the polygon, an optimization is executed by integrating the textures associated with the edge removal and moving the coordinates of the textures.

In first step S1, original polygon data is inputted. The texture is adhered to each plane for the inputted polygon data. The input of the data and the adhesion of the texture are manually performed from the

keyboard 1 or by a method whereby data which has been made in another place and stored in a floppy disk or an MO disk is read out by the FDD 2 or MO drive 3. The polygon data can be also inputted through a network such as an internet.

In step S2, each edge of the inputted polygon data is evaluated for performing the edge removal. In the edge evaluation in step S2, each edge of the inputted polygon data is converted into a numerical value by a method, which will be described hereinlater, and is set to an evaluation value. In step S3, the evaluation values of the edges obtained in step S2 are sorted and the edge having the minimum evaluation value is selected. The processing routine advances to step S4. In step S4, the edge having the minimum evaluation value which was selected in step S3 is removed.

When the edge is removed in step S4, the processing routine advances to step S5. In step S5, the position of the vertex which remains after the edge was removed in step S4 is determined. In step S6, the texture portion which becomes unnecessary in association with the edge removal is removed and the positions of the remaining texture coordinates are determined.

The approximated polygon data which was approximated at a precision of one stage and was subjected to the texture mapping is obtained by the

foregoing processes in steps S2 to S6. The edge removal, the determination of a new vertex, and the process of the texture in association with them are repeated by repeatedly executing the processes in steps S2 to S6. Consequently, the approximated polygon data which was subjected to the texture mapping can be obtained at a desired precision.

When the approximated polygon data which was subjected to the texture mapping at a desired precision in step S6 is obtained (step S7), the processing routine advances to step S8. The obtained approximated polygon data which was texture mapped is drawn on the display apparatus 8. The obtained approximated polygon data which was texture mapped can be also stored into an external memory apparatus such as a hard disk 6 or memory 7, a floppy disk inserted in the FDD 2, or an MO inserted in the MO drive 3. The derived data can be also supplied and stored to another computer system through the network.

The processes in the above flowchart are executed mainly by the CPU 4 in the hardware structure of Fig. 2. Instructions or the like which are necessary during the processes are sent from the input device such as a keyboard 1 or the like to the CPU 4.

Processes regarding a model approximation will now be described. As mentioned above, the approximation of the polygon model is executed by

repeating the edge removal. In this instance, small convex and concave components which do not contribute to a general shape of the model are judged and edges which should be preferentially removed are determined on the basis of the judgement result. In order to select the edges which are preferentially removed, how the edges constructing the model contribute to the general shape, namely, the importance of the edge is evaluated and the removal is executed from the edge of a small evaluation value. In step S2, the importance of the edge is evaluated.

In order to select the edge which is suitable to be removed by obtaining the evaluation value, an evaluation function to evaluate how each of the edges constructing the polygon model contributes to the shape of the polygon model is introduced. The following equation (1) shows an example of the evaluation function. Figs. 3A and 3B are diagrams for explaining the equation (1).

[Equation 1]

$$F(e) = \sum_{i} | aV_i + bS_i | \qquad \ldots (1)$$

where

$$V_i = (N_i \cdot E) \times A_i$$

$$S_i = | E | \times A_i$$

Fig. 3B shows an example in which a part of a spherical polygon model shown in Fig. 3A in which each plane is constructed by a triangle is enlarged. By the equation (1), an edge e constructed by two vertices v_1 and v_2 is evaluated. With respect to the vertices v_1 and v_2 constructing the edge $e(v_1, v_2)$, when sets of planes including them as vertices assume $S(v_1)$ and $S(v_2)$, a range of i is set to $S(v_1) \cup S(v_2)$. That is, $1 \leq i \leq 10$ in the example shown in Fig. 3B. In the diagram, E denotes a vector having the direction and length of the edge e; N_i a unit normal vector of each plane; A_i an area of the plane; and $|E|$ a length of the vector E.

The equation (1) is constructed by two terms. The first term V_i shows a volume amount which is changed when the edge as an evaluation target is removed. The volume amount here denotes a virtual volume of a shape specified by the shape data of the polygon. The second term S_i shows a value obtained by multiplying the planes existing on both sides of the target edge with the length of target edge. It denotes a change amount of the volume of the plane including only the target edge. Coefficients a and b are multiplied to the two terms. The user can select which one of the first term V_i and the second term S_i is preferentially used by properly setting the values of

the coefficients.

The first term V_i largely depends on the peripheral shape of the edge as an evaluation target. On the other hand, the second term S_i depends on the length of target edge and the area of planes existing on both sides of the target edge. In case of a polygon model having a flat shape like a sheet of paper, when the edge e(v_1 and v_2) is removed, the change amount by the term S_i is larger than that by the term V_i. In the polygon model constructed by planes in which all of them have similar shapes and areas, for example, in the model shown in Fig. 3A, the change amount by the term V_i is larger than that by the term S_i.

The value of the equation (1) is calculated with respect to each of the edges constructing the polygon model and the evaluation value for each edge is obtained. In step S3, the calculation values are sorted in accordance with the values and the edge having the minimum evaluation value is selected, thereby obtaining the edge whose contribution to the model shape when the edge is removed is the smallest.

When the importance of the edge is evaluated in step S2, the length of edge is considered. When the evaluation values are the same, the shorter edge can be also set to a target to be removed.

Although the local evaluation value in the polygon model is obtained by the equation (1), each

edge can be also evaluated by a value obtained by adding the evaluation values of the peripheral edges to the evaluation value of a certain target edge. In this case, the evaluation can be performed not only with the peripheral shape of one edge but also with the shape of a wide range. When the area which the user wants to evaluate is wide as mentioned above, the calculation range of the equation (1) can be widened in accordance with such a wide area.

In addition to the evaluation value simply derived by the calculation of the equation (1), the user can give the evaluation value or can operate the evaluation value. Therefore, when there is a portion which the user wants to leave in the shape or a portion which he, contrarily, wants to promptly approximate, the intention of the designer or operator can be reflected to the approximating process by designating such a portion. In this case, the evaluation value is determined by executing a weighted addition by giving a weight coefficient to each of the value operated by the user and the calculated evaluation value.

In this case, the approximation in which the intention of the designer is reflected stronger can be performed depending on a way of giving a weight coefficient, for example, by giving a large weight to the evaluation value designated by the user. On the contrary, when a large weight is given to the

evaluation value obtained by the calculation of the equation (1), an accurate approximation can be performed by a quantitative evaluation of the volume change in shape. In this manner, the change in shape can be freely controlled by the weighting process.

When the evaluation values for the edges of the polygon data are obtained in step S2 as mentioned above, the obtained evaluation values are sorted and the edge having the minimum evaluation value is selected in step S3. When sorting the edges, for example, a quick sorting as a known technique can be used. Other sorting methods can be also obviously used. Since the sorting methods including the quick sorting are described in detail in "Algorithm Dictionary" published by Kyoritsu Publication Co., Ltd. or the like, the description is omitted here. The selected edge having the minimum evaluation value is removed in step S4.

Although the case where the edge having the minimum evaluation value is simply removed has been described here, the removing order of the edges or the edge which is not removed can be also arbitrarily designated. When the edge is not removed, there is no change in shape of such a portion. For example, in the case where it is desirable that the shape is not changed like a portion in which two models are in contact each other, it is sufficient to set a portion

where no edge is removed.

When the edge is removed in step S4, the vertices (v_1 and v_2 in this case) constructing the edge are lost. In step S5, therefore, a new vertex position in association with the edge removal is determined. Figs. 4A and 4B show examples of the vertex position determination. After the edge was removed, either one of the two vertices constructing the edge is left. In this case, the edge $e(v_1$ and $v_2)$ in a layer N in Fig. 4A is removed, thereby obtaining a layer (N + 1) shown in Fig. 4B. The vertex v_1 remains and becomes a new vertex v'.

In this instance, the shape after the edge removal is changed in dependence on the position of the vertex v_1 which remains. Figs. 5A and 5B shows examples of a method of determining the position where the vertex to be left is located. Figs. 5A and 5B show cross sectional views of an edge shape in the polygon data. That is, Fig. 5A shows a case where the edge $e(v_1, v_2)$ constructed by the vertices v_1 and v_2 is formed in a convex shape for the outer edges of v_1 and v_2. Fig. 5B shows a case where the edge $e(v_1, v_2)$ which sandwiched from the upper and lower directions by the outer edges of v_1 and v_2 and is formed in an S shape. In Figs. 5A and 5B, v' indicates a vertex to be left.

In Figs. 5A and 5B, areas S_1 and S_2 shown by hatched regions show volume change amounts when the

edge $e(v_1, v_2)$ is removed and the vertex v' is left. The vertex v' which is left after the edge $e(v_1, v_2)$ was removed is positioned where the volume change amount S_1 on the vertex v_1 side and the volume change amount S_2 on the vertex v_2 side are equal. By arranging the vertex to the position where the volume change amounts on both sides of the removed edge $e(v_1, v_2)$ are equal as mentioned above, the shape after the edge removal can be more approximated to the original shape.

Although the vertex v' which is left and becomes a new vertex is arranged to the position where the volume change amounts on both sides of the edge are equal irrespective of the peripheral shape of the edge which is removed in step S5 in the above description, the invention is not limited to the example. For example, the vertex v' can be also arranged at a position where the volume change upon edge removal is the minimum. As mentioned above, the method of arranging the vertex v' to the position where the volume change amounts on both sides of the edge are equalized and the method of arranging the vertex v' to the position where the volume change is the minimum can be selectively used in accordance with a desire of the user.

In consideration of the peripheral shape of the edge, when the shape has a concave or convex shape, the vertex v' can be also arranged at a position where

the volume change after the edge removal is the minimum. When the periphery has an S-character shape, the vertex v' can be arranged at a position where the volume change amounts on both sides of the edge are equalized. In this case, the position of the vertex v' is deviated to either one of the ends of the edge in case of the concave or convex shape. In case of the S-character shape, the vertex v' is arranged in the middle of the S character. Thus, both of an effect to suppress the volume change and an effect to absorb the continuous changes like an S character by the plane can be derived.

For example, an area in which a change having a small S-character shape continues like a saw tooth can be approximated by one plane in a general shape. A portion having a large change except the S-character shape can be approximated by a shape which is closer to the original shape. In the approximation in which the shape has a priority, such a setting is also possible. The approximating methods can be selectively used in accordance with the intention of the user.

It is also possible not to change the vertex position remaining after the edge removal from the vertex position before the edge removal. That is, in the example shown in Figs. 4A and 4B , for example, after the edge $e(v_1, v_2)$ was removed, only the vertex v_1 is left as a new vertex v' without changing the

position from the position before the removal. This is effective means when it is desirable not to move the position of a target vertex because the target vertex exists at a contact point with the other model or the like.

When the edge is evaluated and removed and the new vertex in association with the edge removal is determined in steps up to step S5, a process regarding the texture adhered to each plane of the polygon model is executed in step S6. Figs. 6A and 6B schematically show examples in which image data (texture) is allocated to a certain plane on the polygon model. Fig. 6A shows a polygon model itself comprising vertices V_1 to V_9. It shows that when an edge $e(v_3, v_6)$ shown by a broken line is removed from the model shown in the left diagram, the model is approximated to a shape shown in the right diagram.

Fig. 6B shows a state in which a texture is adhered to the polygon model shown in Fig. 6A. In this instance, for easy understanding, image data based on a portrait is used as a texture. Coordinates vt_1 to vt_9 in Fig. 6B correspond to the vertices v_1 to v_8 in Fig. 6A, respectively. Fig. 6B, therefore, shows that the coordinates vt_1 to vt_4 in the diagram on the left side are changed as shown in a diagram on the right side in association with the removal of the edge $e(v_3, v_6)$ in Fig. 6A.

The vertex v_6 is removed by the approximation of the polygon model and the two vertices v_3 and v_6 in this model are integrated to one vertex v_3. In association with it, by removing the edge $e(v_3, v_6)$ comprising v_3 and v_6, triangular areas on both sides including such an edge is lost. In this instance, unless the loss of those triangular areas is considered, the image data comprising the texture coordinates vt_3, vt_4, and vt_6 and the image data comprising vt_3, vt_5, and vt_6 are lost.

As shown by the texture in the diagram on the right side in Fig. 6B, therefore, it is necessary to execute an integration and a position movement to the texture in accordance with the approximation of the edge removal. Thus, the continuous image data on the approximated model surface can be reproduced.

In this example, the vertices v_3 and v_6 are integrated on the polygon model and the vertex v_3 remains. The remaining vertex v_3 is set to a vertex v_3'. The position of the vertex v_3' is arranged at a predetermined distribution ratio t on the coordinates between the edge $e(v_3, v_6)$ comprising v_3 and v_6 before approximation. In this case, the coordinates of the vertex v_3' can be calculated by $[(1 - t) \times v_3 + t \times v_6]$. When $0 \leq t \leq 1$, the distribution coefficient t exists on the edge straight line of the edge $e(v_3, v_6)$ before approximation and, when $t < 0$ or $1 < t$, t exists out of

the edge $e(v_3, v_6)$. By changing a value of t, therefore, a shape change amount after the model was approximated by the edge removal can be controlled.

As mentioned above, the vertices v_3 and v_6 are integrated on the polygon model and are set to the vertices v_3' and v_3' is arranged between the vertex v_3 and the vertex v_6. The texture coordinates vt_3 and vt_6 corresponding to those two vertices are, therefore, also integrated to the coordinates vt_3 after approximation and are set to coordinates vt_3'. The coordinates vt_3' are arranged between the coordinates vt_3 and vt_6 before approximation.

Figs. 7A and 7B schematically show the integration of vertices and the integration of texture coordinates in association with the edge removal. Fig. 7A shows an example in which the integrated vertex v_3' is arranged to the position calculated by $[(1 - t) \times v_3 + t \times v_6]$ in association with the removal of the edge $e(v_3, v_6)$. A distribution of the remaining texture coordinates can be obtained in a manner similar to the arrangement of the vertex v_3' based on the distribution t. That is, as shown in Fig. 7B, as for the distribution of the remaining texture coordinates vt_3', by calculating $[(1 - t) \times vt_3 + t \times vt_6]$ in a manner similar to the distribution t between the above vertices v_3 and v_6, an image can be distributed in a form according to a change in model shape to which the

image is adhered. Thus, as shown in the diagram on the right side of Fig. 6B, the textures can be continuously adhered to the polygon model.

In this instance, when the position of the coordinates vt_3 of the texture data corresponding to the vertex v_3 on the polygon model is not changed in accordance with the change in model shape as mentioned above, for example, in the texture shown in Fig. 6B, an image existing at the position of the face corresponding to the triangular plane including the removed edge $e(v_3, v_5)$ cannot be adhered to the model.

With respect to an original polygon model shown in Fig. 8A, for example, when the coordinates vt_5 on the texture allocated to the vertex v_5 are made correspond to the remaining vertex v_3 side from the integration relations of vertices after the removal of the edge e without considering the image data allocated to the triangular plane which disappears at the time of the removal of the edge $e(v_3, v_5)$, the portion of the face disappears as shown in Fig. 8B. Further, when the coordinates of vt_3 before the edge removal are succeeded as they are after the edge removal without considering the integration relation of the vertices at the time of the removal of the edge e, as shown in Fig. 8C, since the coordinates of the vertex v_3 change after the removal of the edge e and an area of each plane changes, the resultant image to which the texture was

adhered is distorted. That is, the texture data also needs to be changed in accordance with the change in plane and change in model vertex position due to the edge removal.

When the texture is adhered to the polygon model, there is a case where not only one texture but also a plurality of different textures are allocated to the model. In this case, a boundary in which the texture is switched from a certain texture to another texture exists.

In case of adhering the texture to the polygon model, as mentioned above, the texture is allocated to each vertex of the model. Even in the boundary of the texture, therefore, the boundary is allocated to each vertex constructing the edge of the model. Further, as mentioned above, the approximation of the model is performed by repeating the edge removal only a desired number of times. In this instance, if the texture area allocated to the edge as a target of the removal is in the texture, as shown in Figs. 6 and 7 mentioned above, the model can be approximated while holding a continuity of the image.

However, when the area of the image allocated to the edge as a removal target exists just on the boundary of the image, the polygon model is approximated by the edge removal and since the vertex position is moved, a plurality of textures are mixed

and the shape of texture is broken. To prevent it, it is necessary to make a discrimination so as not to break the image boundary at the time of the edge removal and to decide sizes of a change of the outline portion by the edge removal.

As shown in Fig. 9A, two different textures of a texture comprising the image of the hatched portion and a texture comprising the image of the face portion mixedly exist and adhered to one polygon model. Fig. 9B shows a certain continuous edge train in the model shown in Fig. 9A. In the model shown in Figs. 9A and 9B, for example, when the edge $e(v_4, v_5)$ comprising the vertices v_4 and v_5 is removed and the vertex v_4 is left after the removal, when executing a process to arrange a vertex v_4' based on the vertex v_4 to the middle position of the edge $e(v_4, v_5)$ as a removal target, an outline portion of the edge changes as shown in Fig. 9C.

In this case, since the outline portion of the face image has also been adhered to each of the vertices v_3 to v_6, as shown in Fig. 9D, the shapes of the two adhered images are broken. In this example, the shape of the lower portion of the face picture is largely changed and the image of the hatched region increases. As mentioned above, in the edges of the model to which the outline portion of the image is allocated, if the edge removal is simply repeated as

mentioned above, the quality after the approximation is deteriorated.

To prevent it, a removal evaluating function of the edge as a boundary portion of the texture is introduced and when the shape of the texture boundary is largely changed by the edge removal, it is necessary to use any one of the following methods. Namely, as a first method, the relevant edge is not removed. As a second method, although the edge is removed, a movement amount of the vertex position after the removal is adjusted. The following equation (2) is used as a removal evaluating function of each edge in this instance. Fig. 10 shows a diagram for explaining the equation (2).

$$F(e) = \sum_{i} \left| (N_i \cdot E) \times L_i \right| \qquad \ldots (2)$$

In the equation (2), E denotes the vector having the direction and length of the edge e, Ni indicates the normal vector of the edge, and Li the length of edge. A range of i corresponds to the whole edge of the boundary lines existing before and after the edge as a removal target. The equation (2) denotes an area change amount when the edge of the boundary portion is removed. Therefore, when the calculation value of the equation (2) is large, a change of the outline portion by the edge removal is large.

Namely, when the calculation value of the equation (2) is large, the area change in the outline portion of the texture increases, so that there is a fear of occurrence of the breakage of the texture shape. To prevent it, there is a method whereby the relevant edge is not removed like the foregoing first method. However, like the foregoing second method, there is also a method whereby the texture coordinates after the edge removal are moved within a range where the value of the equation (2) is smaller than the designated value, thereby consequently decreasing the change amount of the outline portion. By using the second method, the breakage of the texture after the approximation can be suppressed.

As mentioned above, the approximated polygon model to which the texture having a desired precision is adhered can be obtained. In this case, when the texture is adhered to the original model, there is no need to again adhere the texture to the model after completion of the approximation and the approximated model with the texture can be automatically obtained.

As mentioned above, the approximated model obtained by repeating the processes in steps S2 to S6 is stored into the external storing apparatus such as hard disk 6 or memory 7. However, when displaying in step S8, the approximated model stored in the external storing apparatus is read out, drawn, and displayed to

the display apparatus 8. As already described in the foregoing prior art, in this display, for example, when the model is displayed as a small image on the picture plane because it is arranged at a remote location or when the observer doesn't pay attention to the model because it is out of the target point on the picture plane, the model is switched to the model of a layer that was more approximated and the image is displayed.

Upon switching of the approximated model, if the model is suddenly switched to the model in which a degree of approximation largely differs, a sudden change occurs in the shape of the displayed model at a moment of the switching and a feeling of disorder is given to the observer.

To prevent that the feeling of disorder is given, it is sufficient that a number of models whose approximation degrees are slightly changed are prepared and stored into the external storing apparatus and the display is performed while sequentially switching those models. In this case, however, since an amount of models to be stored increases, it is no efficient. Therefore, to realize a smooth continuous conversion even in the small number of models, it is sufficient to interpolate the model among the discrete layers and to obtain the model of the middle layer.

For example, in the example shown in Figs. 4A and 4B mentioned above, the vertex after the edge $e(v_1,$

v_2) was removed is set to v'. However, as for the vertex v', it is considered that the vertices v_1 and v_2 in the edge $e(v_1, v_2)$ approach each other and become the vertex v'. Namely, the vertices v_1 and v_2 are consequently integrated to the vertex v'. As mentioned above, since the correspondence relation of the vertices before and after the edge removal is known, the data between the data before and after the edge removal can be obtained by an interpolation from the data before and after the edge removal by using the correspondence relation of the vertices.

Such a forming method of the approximated model in the middle layer between the discrete layers has already been described in detail in Japanese Patent Application No. 6-248602 regarding the proposition of the present inventors.

Figs. 11A to 11C show the formation of the approximated model of the middle layer using the correspondence relation of the vertices between two layers as mentioned above. In Figs. 11A to 11C, a layer before the edge removal is set to a layer N as shown in Fig. 11A and a layer after the edge removal is set to a layer N+1 as shown in Fig. 11C, thereby obtaining a model of a middle layer N' shown in Fig. 6B from those two layers.

In the example, the vertices v_1 and v_2 constructing the edge $e(v_1, v_2)$ of the layer N are

integrated to v_1 in the layer N+1 and the deleted vertex v_2 is integrated to v_1. From the correspondence relation of the vertices, in the middle layer N', the positions of vertices v_1' and v_2' constructing an edge $e'(v_1', v_2')$ corresponding to the edge $e(v_1, v_2)$ of the layer N can be obtained by the linear interpolation between the layers N and N+1. Although the example in which one middle layer is obtained is shown here, a degree of linear interpolation is changed in accordance with a desired number of middle layers and a plurality of middle layers can be obtained. The formation of the approximated model of the middle layer can be performed in a real-time manner in accordance with a situation in which the model is displayed.

Although the case where the approximated model of the middle layer is formed and displayed in a real-time manner while displaying the model has been described here, the invention is not limited to such an example. For instance, it is also possible to construct in a manner such that the approximated model of the middle layer is previously formed and stored in the external storing apparatus and the stored approximated model of the middle layer is read out at the time of the display.

Although the case where one edge is removed has been mentioned as an example here, since the edge removal is repeated a plurality of number of times in

the approximation of the actual model, one vertex of a certain layer corresponds to a plurality of vertices of another layer which is closer to the original model. By using the correspondence relation of the vertices in those two layers as mentioned above, the vertices of the model can be made correspond among all of the layers. The model of the middle layer is obtained on the basis of the correspondence relation of the vertices derived as mentioned above.

As mentioned above, since the coordinates of the image data in the texture are allocated to each vertex of each model, in a manner similar to the case of the vertices of such a model, the model to which the texture was adhered in the middle layer can be obtained by the interpolation of the texture coordinates vt_1 and vt_2 allocated to the vertices v_1 and v_2, respectively. By such a process, the models in a range from the original model to the most approximated model can be smoothly continuously obtained.

By the above processes, the discrete hierarchical approximated model can be obtained and the model of the middle layer can be also obtained. The approximated model obtained and stored as mentioned above is switched in accordance with the size, position, speed, and attention point of the viewer of the apparent model on the picture plane in the display apparatus 8 and is displayed in step S8. Figs. 7A and

7B show examples of the approximated model derived by the embodiment.

Fig. 12 schematically shows an example of the processing results according to the embodiment. In this example, the original model is a sphere comprising 182 vertices, 360 planes, and 279 texture coordinates. An image of the earth is adhered as a texture to the sphere. It is approximated for the original model by reducing every 60% in comparison of the number of vertices. Fig. 13 shows a wire frame state of a model when the texture of the same approximated model is not adhered. In Fig. 12, since the image is consistently held, it is difficult to know a degree of approximation, in the approximated state before the texture image is adhered as shown in Fig. 13, the progress of the approximation can be clearly seen.

As more specifically shown in Fig. 13, by using the present invention, even if the number of vertices is reduced to 36% or 21.6% of the original model, the hierarchical approximated model can be obtained without losing the general shape which the original model has.

Although the case where the texture image is adhered to the polygon model has been described above, the invention can be also obviously applied to the case where the texture image is not adhered. In this case, step S6 can be omitted in the flowchart shown in Fig. 1

mentioned above.

As described above, according to the invention, when image data (texture) is adhered to geometric data such as polygon data which is used in the CG, the model can be approximated to a desired degree of details while preventing the breakage of the texture shape or a apparent deterioration of the quality. A troublesomeness such that after the model was approximated, the texture is newly adhered can be also omitted.

According to the invention, therefore, there is an effect such that the geometric model which is used in the CG can be approximated in a state in which the texture is adhered. There is also an effect such that not only the model is merely approximated but also the breakage of the shape of the texture in the approximation result can be suppressed.

By using the geometric model approximated by the method based on the invention, in the drawing of the CG, there is an effect such that a request for drawing of a high speed and a high picture quality can be satisfied.

Further, according to the invention, an importance degree of each edge constructing the geometric model which is used for the CG can be evaluated by an evaluation value. There is an effect such that the geometric model can be approximated by

preferentially removing the edge of a low evaluation value of the edge.

According to the invention, the position of the vertex remaining after the edge was removed can be determined so as to suppress a change in general shape. Thus, there is an effect such that a feeling of disorder upon looking when drawing by using the approximated model can be suppressed.

According to the invention, figure data which is used in the CG can be approximated by a plurality of resolutions. There is an effect such that by using the figure data derived by the invention, both of the drawing at a high speed and the drawing with a high quality can be satisfied.

The present invention is not limited to the foregoing embodiments but many modifications and variations are possible within the spirit and scope of the appended claims of the invention.

WHAT IS CLAIMED IS:

1. A hierarchical approximating method of shape data for approximating shape data into data of a desired resolution, comprising the steps of:

evaluating a degree of importance of each edge constructing said shape data;

removing an unnecessary edge on the basis of a result of an evaluation of said edge; and

determining a position of a vertex after said unnecessary edge was removed.

2. A hierarchical approximating method of shape data with an image for approximating shape data to which image data was adhered into data of a desired resolution, comprising the steps of:

deciding whether which edge of the shape data is removed at the time of the approximation;

deciding a position of a new vertex in said shape data after an edge removal performed on the basis of said decision about the edge removal; and

performing a removal of an unnecessary vertex in the image data adhered to said shape data and a movement of vertices on said image data in accordance with a position of a new vertex in said shape data in accordance with outputs from said edge removal deciding step and said vertex movement deciding step.

3. A method according to claim 1 or 2, wherein said shape data is 3-dimensional polygon data.

4. A method according to claim 1 or 2, wherein in said evaluation of the edge, a change amount of a volume of a shape specified by said shape data when said edge is removed is obtained and it is decided that as said volume change amount is small, the degree of importance of said edge is small.

5. A method according to claim 1 or 2, wherein in said evaluation of the edge, a change amount of a volume specified by said shape data when said edge is removed and a length of said edge are obtained, it is decided that as said volume change amount is small, the degree of importance of said edge is small, and it is decided that as said area change amount is small, the degree of importance of said edge is small, and it is also decided that as said length of the edge is small, the degree of importance of said edge is small.

6. A method according to claim 4 or 5, wherein in said evaluation of the edge, said degree of importance of the edge and a degree of importance of an edge that is separately given by a user are used, and it is decided that from an edge in which both of the degree of importance of said edge and the degree of

importance of said edge which was separately given are low, the degree of importance of said edge is small.

7. A method according to claim 1 or 2, wherein said vertex is arranged at a position where said volume change amounts in association with said edge removal are equal on the vertex side of one end and the vertex side of another end constructing said edge to be removed for the position of said vertex.

8. A method according to claim 1 or 2, wherein said vertex is arranged at a position where said volume change amount by said edge removal is minimized.

9. A method according to claim 1 or 2, wherein when the shape of the portion where said edge is removed is a concave or convex shape, said vertex is decided at a position where said volume change amount is minimized, and when the shape of the portion where said edge is removed is a S-character shape, said vertex is arranged at a position where said volume change amounts are equalized on the vertex side of one end and the vertex side of another end constructing said edge to be removed for said vertex position.

10. A method according to claim 1 or 2, wherein said vertex is arranged at a position where the vertex

remaining after said edge removal is located at the same position as that before said edge removal.

11. A method according to claim 2, wherein in said step of deciding the removal and movement of said image data, the vertex of said image data corresponding to the vertex of the edge to be removed in accordance with an output from said step of deciding said edge removal is removed.

12. A method according to claim 2, wherein in said step of deciding the removal and movement of said image data, a new position of the corresponding vertex on said image data is determined in accordance with an output of said step of deciding the vertex movement and in accordance with the movement of the vertex to the new position in said shape data.

13. A method according to claim 12, wherein in said step of deciding the removal and movement of said image data, an amount of movement of the vertex of said image data is obtained by interpolation from coordinates between two vertices on the image data which inherently correspond to the removed edge.

14. A method according to claim 12 or 13, wherein in the interpolation of the vertex of the image data

which is decided in said step of deciding the removal and movement of said image data, the movement amount is obtained by using a linear interpolation.

15. A method according to claim 12, 13, or 14, wherein in said step of deciding the removal and movement of said image data, an interpolation coefficient of the vertex movement used when deciding said vertex movement is used as it is and the movement amount of the vertex of the image data is decided in accordance with an output from said step of deciding the vertex movement.

16. A method according to claim 2 or 11, wherein in said step of deciding the removal and movement of said image data, when the edge as a removal target exists on an outline of said image data, if an area change amount after the edge removal exceeds a predetermined range, the edge as said removal target is not removed.

17. A method according to claim 2 or 12, wherein in said step of deciding the removal and movement of said image data, an area change amount of said image data to be influenced by the approximation is obtained and the movement amount of said image data coordinates is decided so that said change amount lies within a

predetermined range.

18. An approximating apparatus of figure data for approximating shape data to a data of a desired resolution, comprising:

evaluating means for evaluating a degree of importance of each edge constructing said shape data;

edge removing means for removing an unnecessary edge on the basis of a result of an evaluation of said edge; and

vertex position deciding means for deciding a position of a vertex after said unnecessary edge was removed.

19. A hierarchical approximating apparatus of shape data with image data for approximating shape data to which image data was adhered into data of a desired resolution, comprising:

edge removal deciding means for deciding which edge of the shape data is removed at the time of an approximation;

vertex movement deciding means for deciding a position of a new vertex in the shape data after the edge removal; and

image data removal movement deciding means for performing a removal of the unnecessary vertex in the image data adhered to said shape data and a

movement of the vertex on said image data in accordance with the position of the new vertex in said shape data in accordance with outputs from said edge removal deciding means and said vertex movement deciding means.

ABSTRACT OF THE DISCLOSURE

Polygon data inputted in the first step is subjected to evaluation of all edges of the polygon data on the basis of a volume change due to an edge removal by a predetermined evaluating function in the second step. The edges are sorted on the basis of an evaluation value in the third step. In the fourth step, the edge of a small evaluation value is determined to be an edge of a small influence on a general shape and is removed. In the fifth step, a new vertex is determined from the loss of vertex by the edge removal. In the sixth step, a movement of texture coordinates and a removal of the texture after the edge removal are executed on the basis of the area change of the texture due to the edge removal by a predetermined evaluating function. In the seventh step, by repeating the processes in the second to sixth steps, a polygon model approximated to a desired layer can be obtained.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In the Patent Application of Junji HORIKAWA et al.	Prior Art Unit: 2724
Serial No. Not Yet Assigned	Prior Examiner: A. Do
Filed: Herewith	
For: COMPUTER ANIMATION GENERATOR	

SUBMISSION OF FORMAL DRAWINGS AND LETTER TO THE OFFICIAL DRAFTSPERSON

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Attached please find a copy of the proposed changes to the drawing(s) in this application, for which the approval of the Examiner is requested. Specifically, Figure 2 has been amended to indicate numerals 1 through 9. A complete set of new formal drawings is also enclosed.

Respectfully submitted,

DATE: August 4, 1999

Ronald P. Kananen
Registration No. 24,104

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Fig. 2

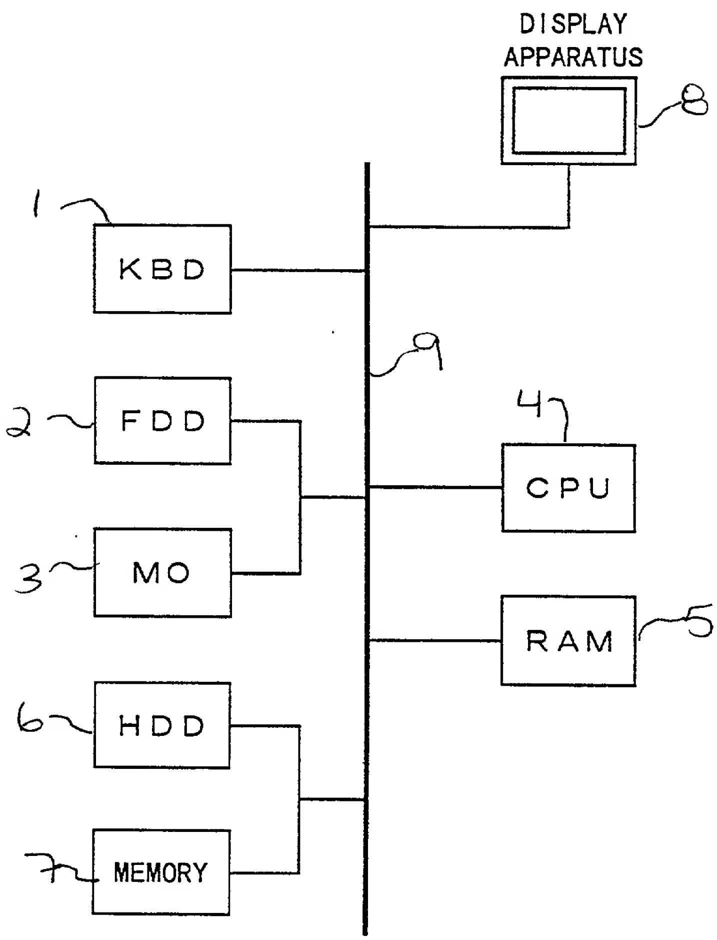


Fig. 1

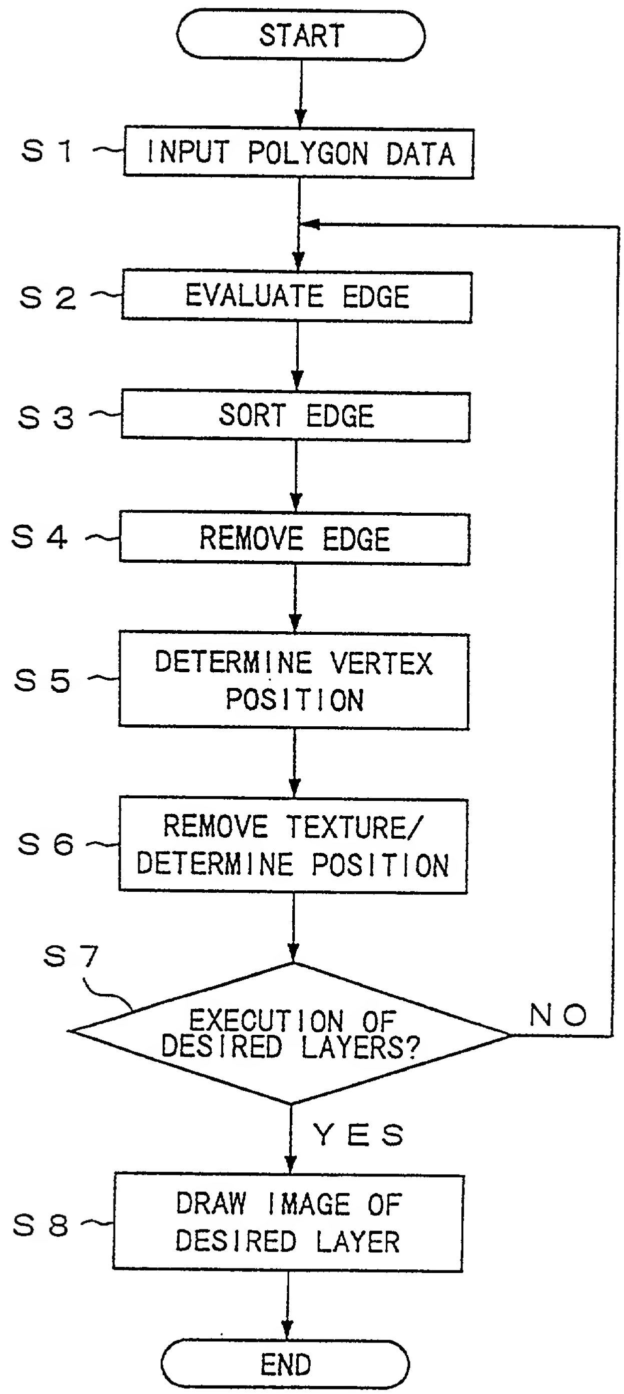

START
S 1
INPUT POLYGON DATA
S 2
EVALUATE EDGE
S 3
SORT EDGE
S 4
REMOVE EDGE
S 5
DETERMINE VERTEX POSITION
S 6
REMOVE TEXTURE/ DETERMINE POSITION
S 7
EXECUTION OF DESIRED LAYERS?
NO
YES
S 8
DRAW IMAGE OF DESIRED LAYER
END

Fig. 2

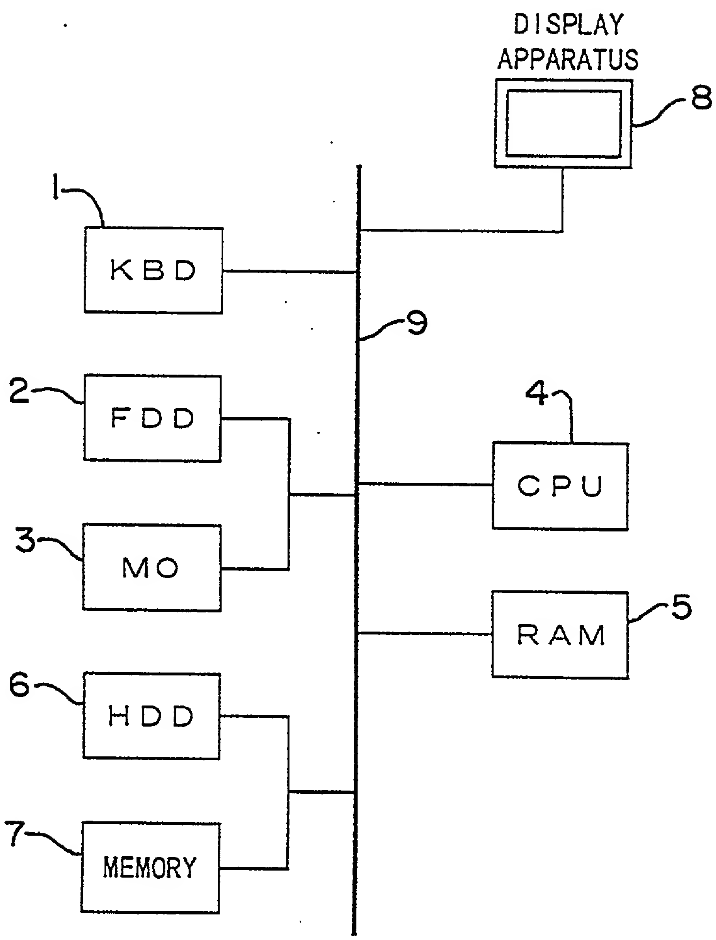


Fig. 3A

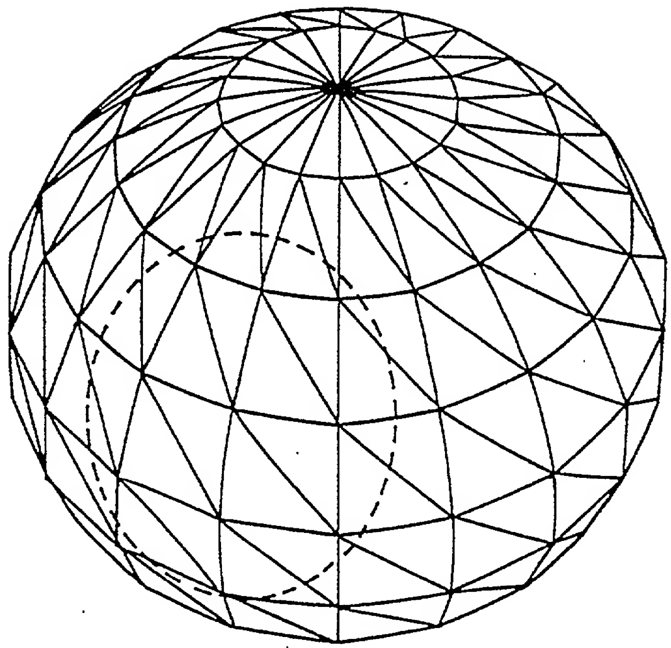
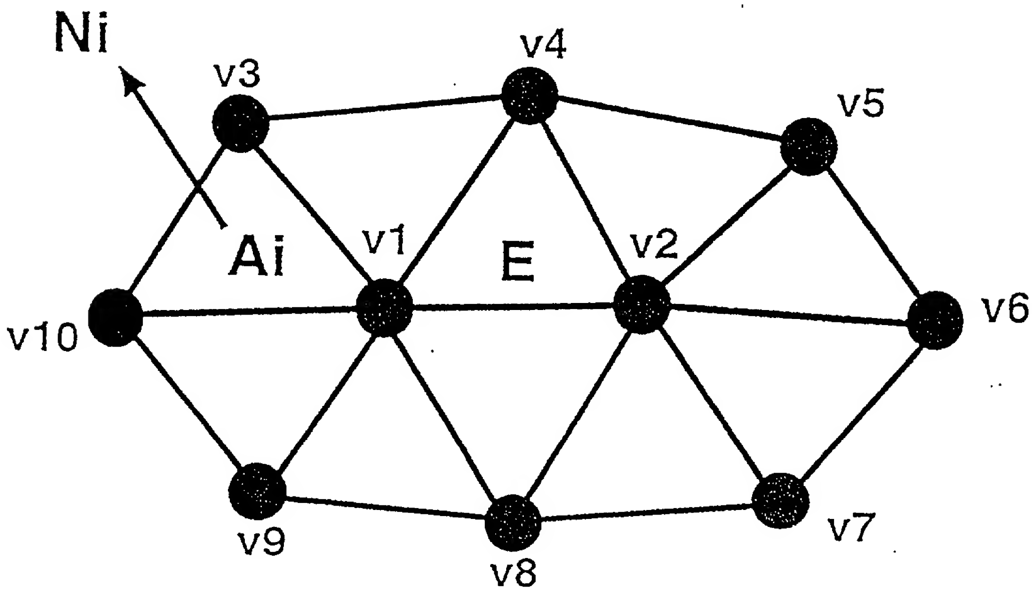


Fig. 3B



E:edge, Ni:normal, Ai:area,
v1~v10:vertices

Fig. 4A

Fig. 4B

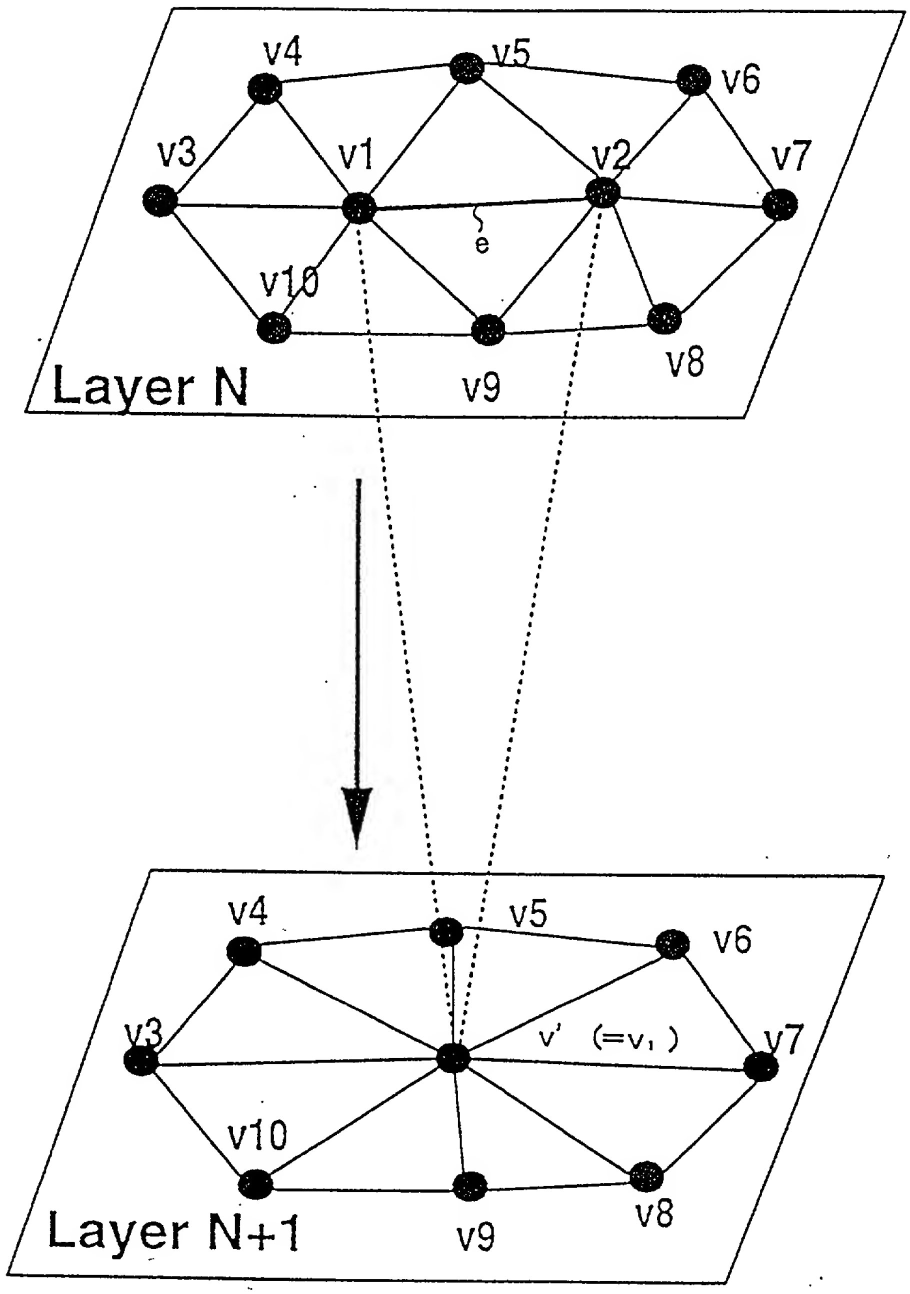

v4
v5
v6
v3
v1
v2
v7
e
v10
v9
v8
Layer N
v4
v5
v6
v3
v' (=v1)
v7
v10
v9
v8
Layer N+1

Fig. 5A

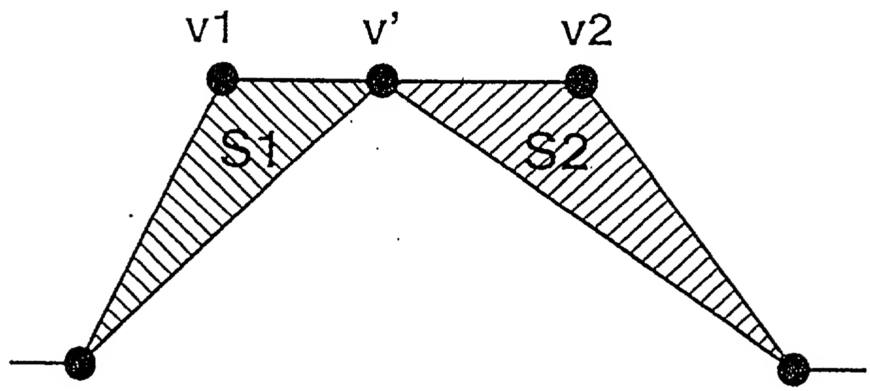


Fig. 5B

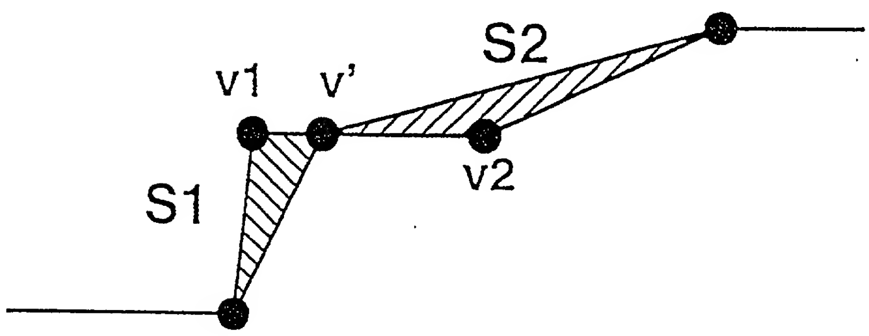


Fig. 6A

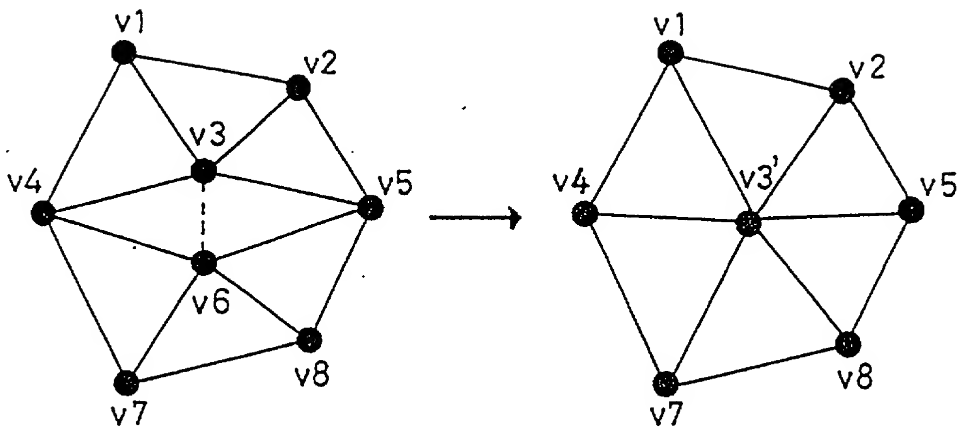

v1
v2
v3
v4
v5
v6
v7
v8
v1
v2
v3'
v4
v5
v7
v8

Fig. 6B

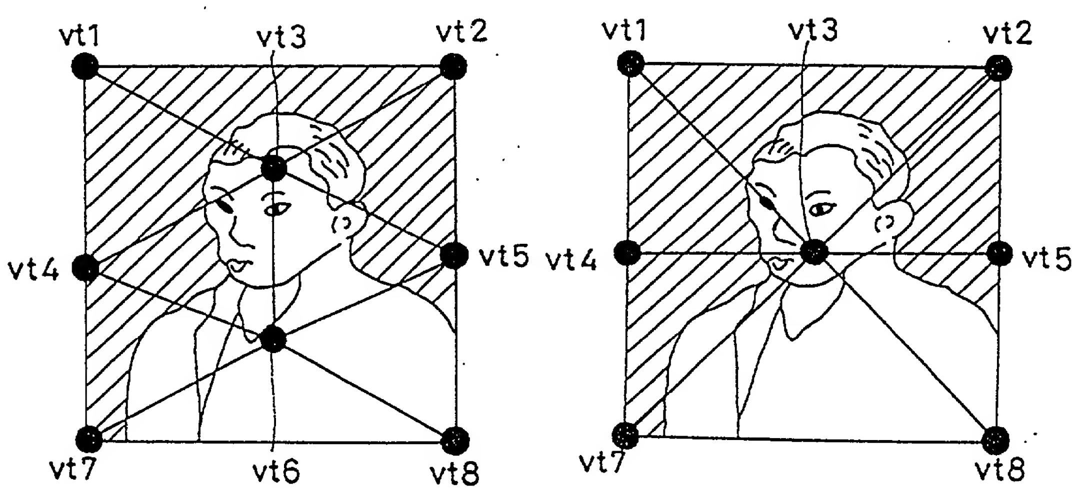

vt1
vt3
vt2
vt4
vt5
vt7
vt6
vt8
vt1
vt3
vt2
vt4
vt5
vt7
vt8

Fig. 7A

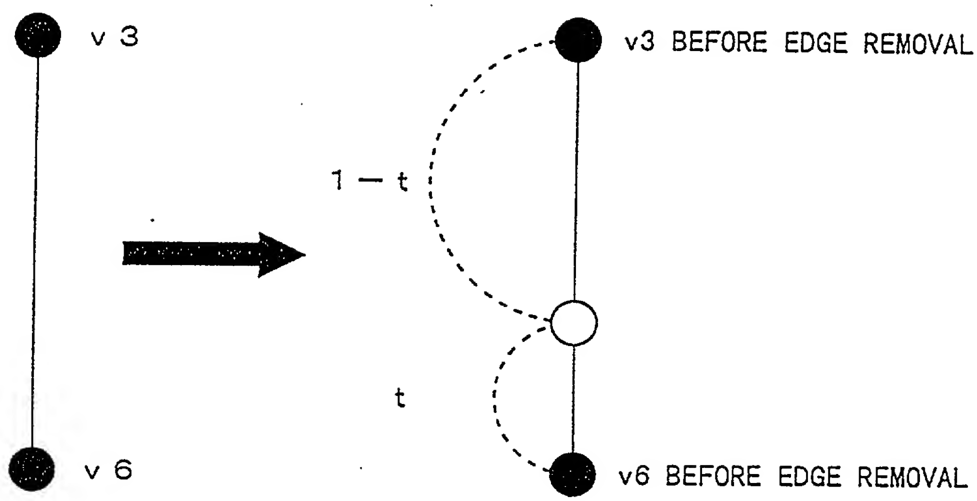

v 3
v 6
v3 BEFORE EDGE REMOVAL
1 − t
t
v6 BEFORE EDGE REMOVAL

Fig. 7B

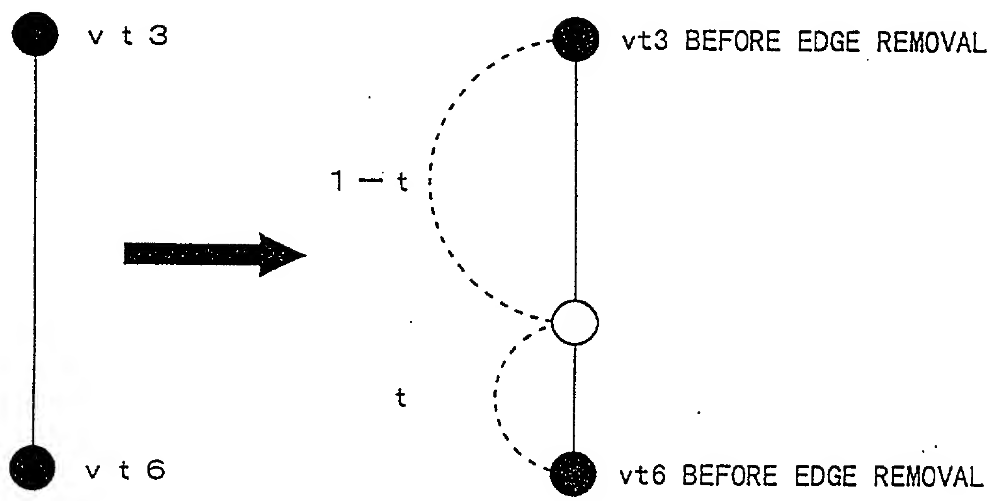

v t 3
v t 6
vt3 BEFORE EDGE REMOVAL
1 − t
t
vt6 BEFORE EDGE REMOVAL

Fig. 8A

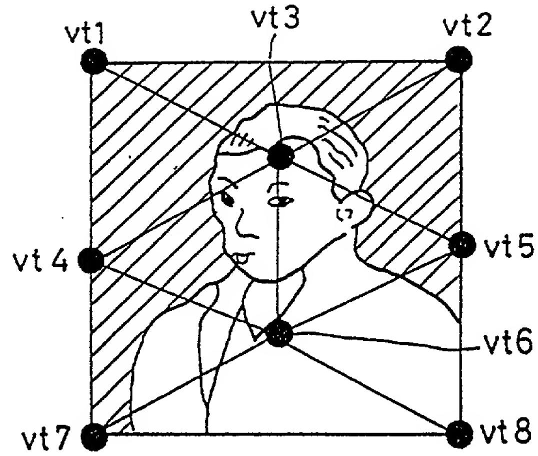


Fig. 8B

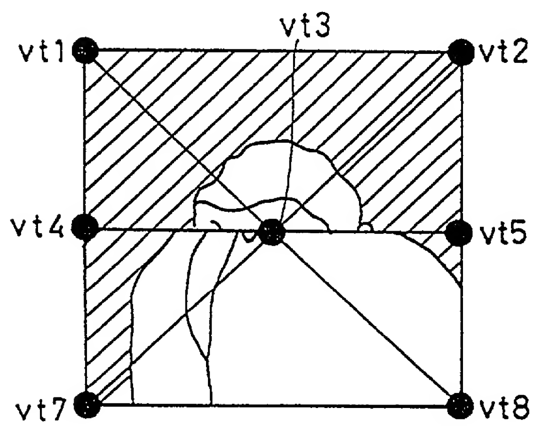


Fig. 8C

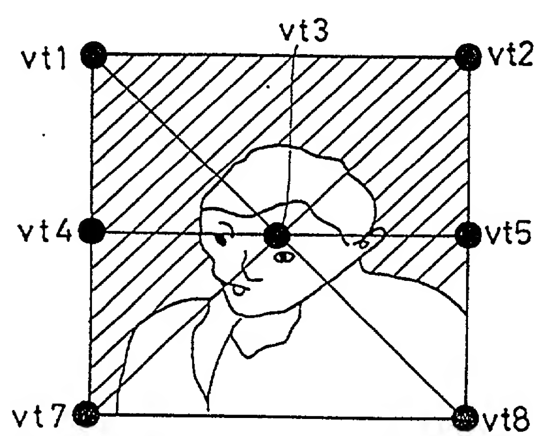


Fig. 9A

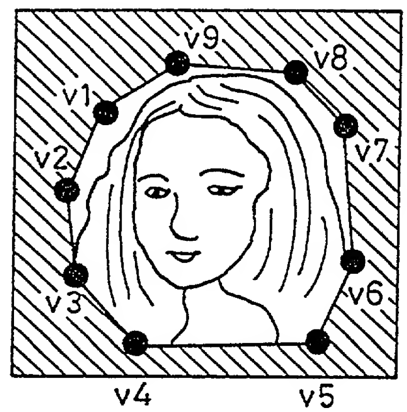


Fig. 9B

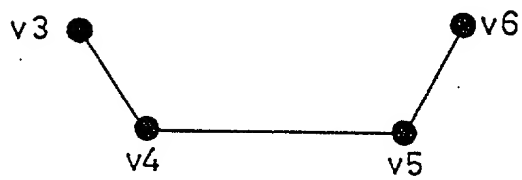


Fig. 9C

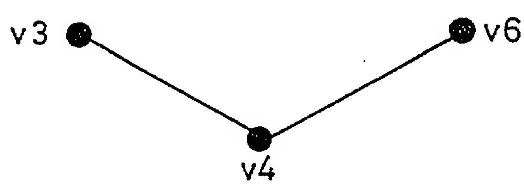


Fig. 9D

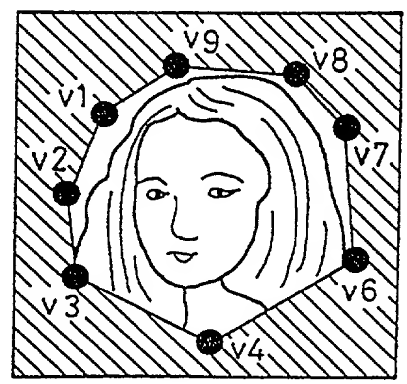
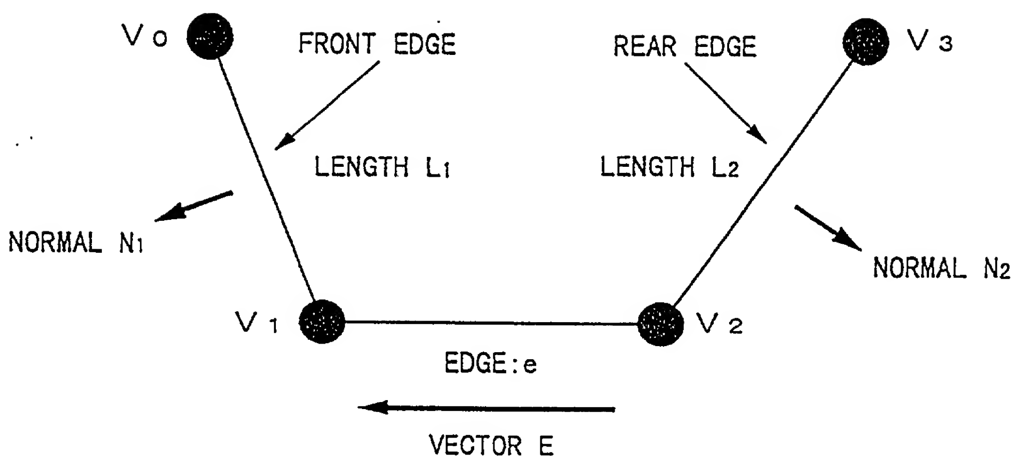


Fig. 10



V o
FRONT EDGE
REAR EDGE
V 3
LENGTH L1
LENGTH L2
NORMAL N1
NORMAL N2
V 1
V 2
EDGE:e
VECTOR E

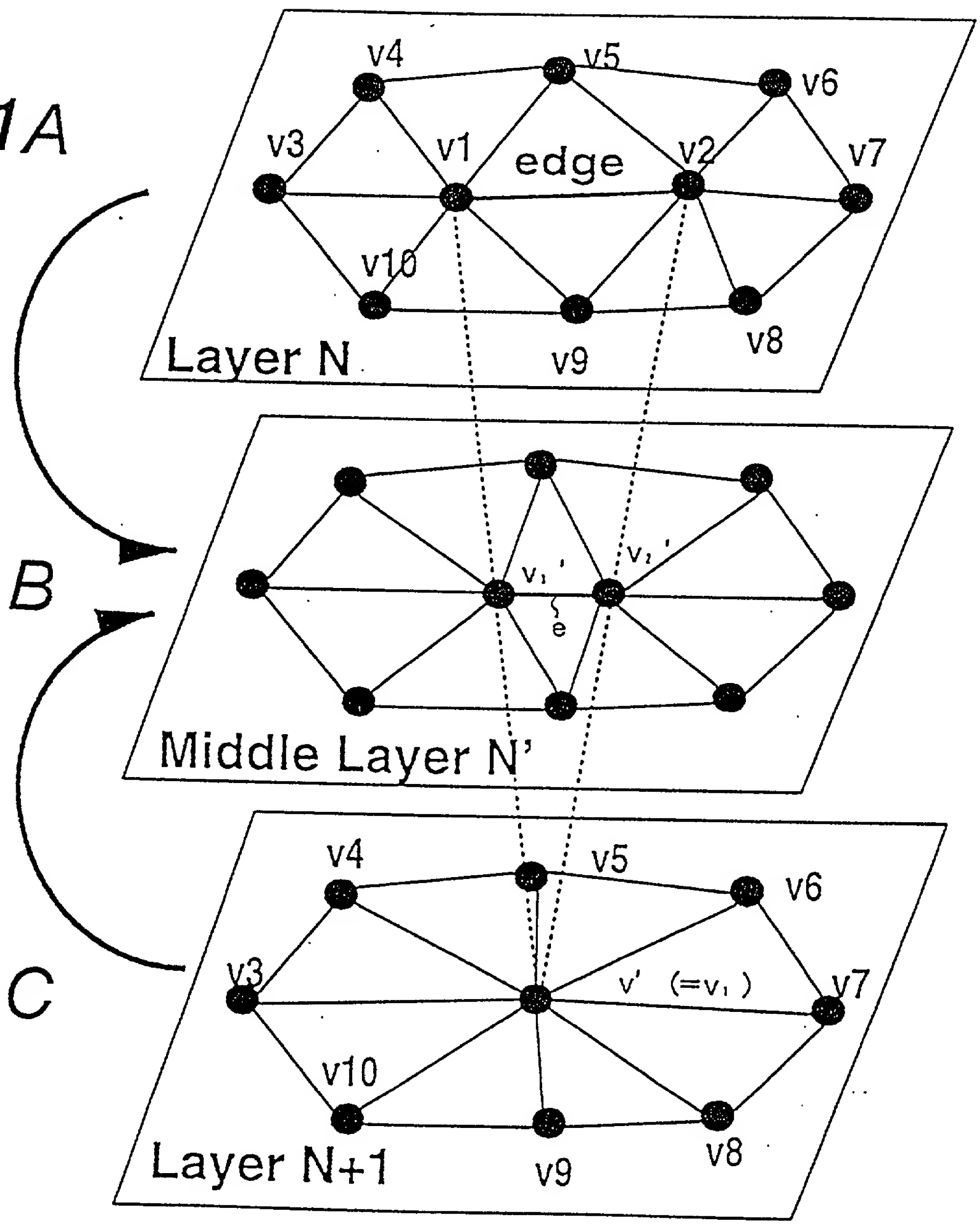
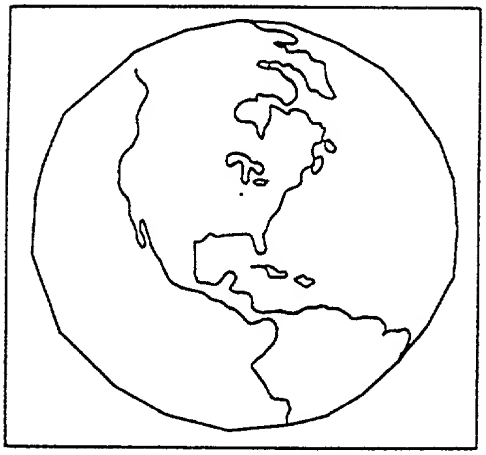


Fig. 11A

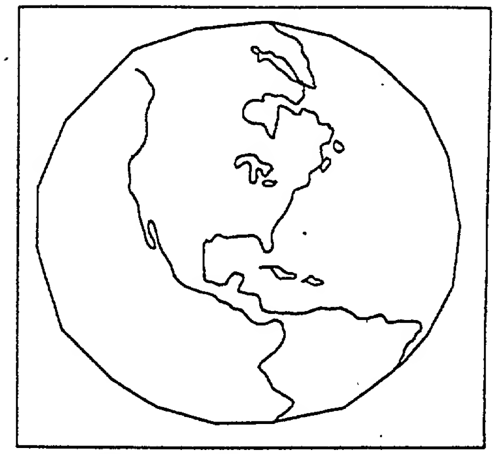
Fig. 11B

Fig. 11C

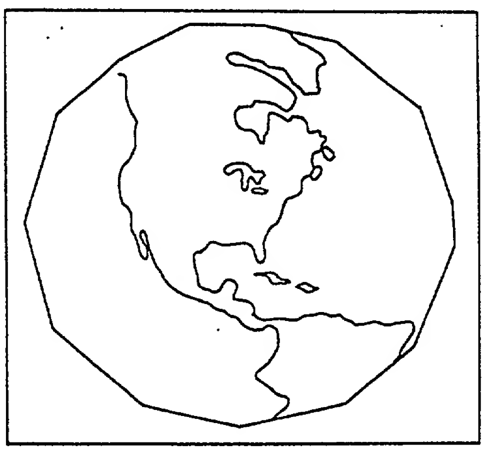
Fig. 12



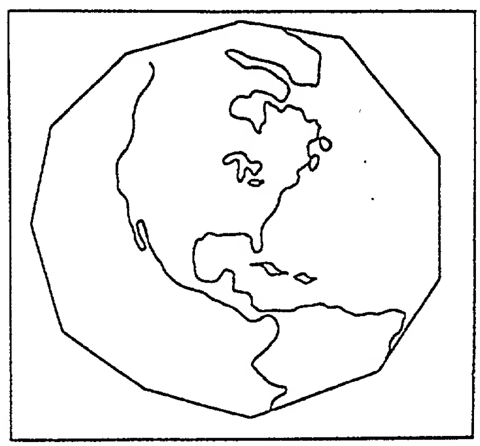
original:182vertices



60%:109vertices

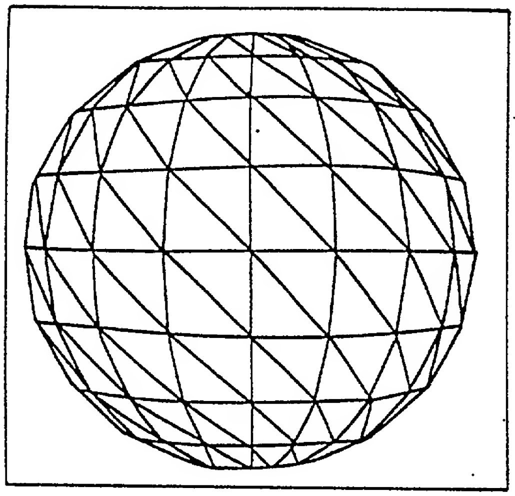


36%:66vertices

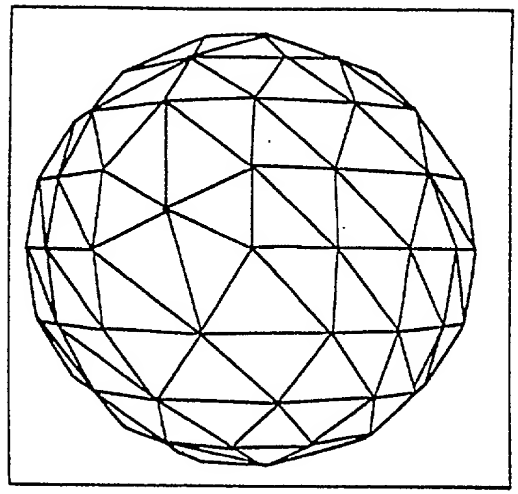


21. 6%:39vertices

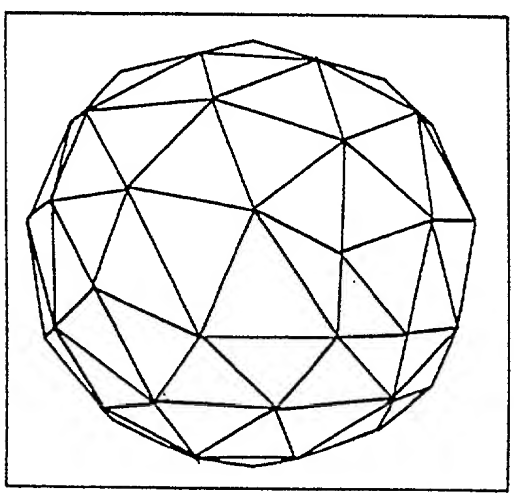
Fig. 13



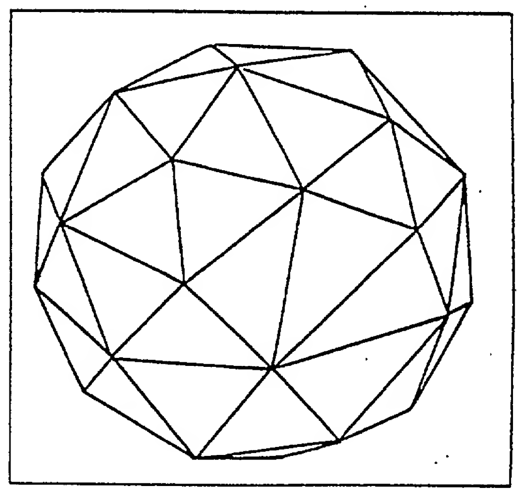
original:182vertices



60%:109vertices

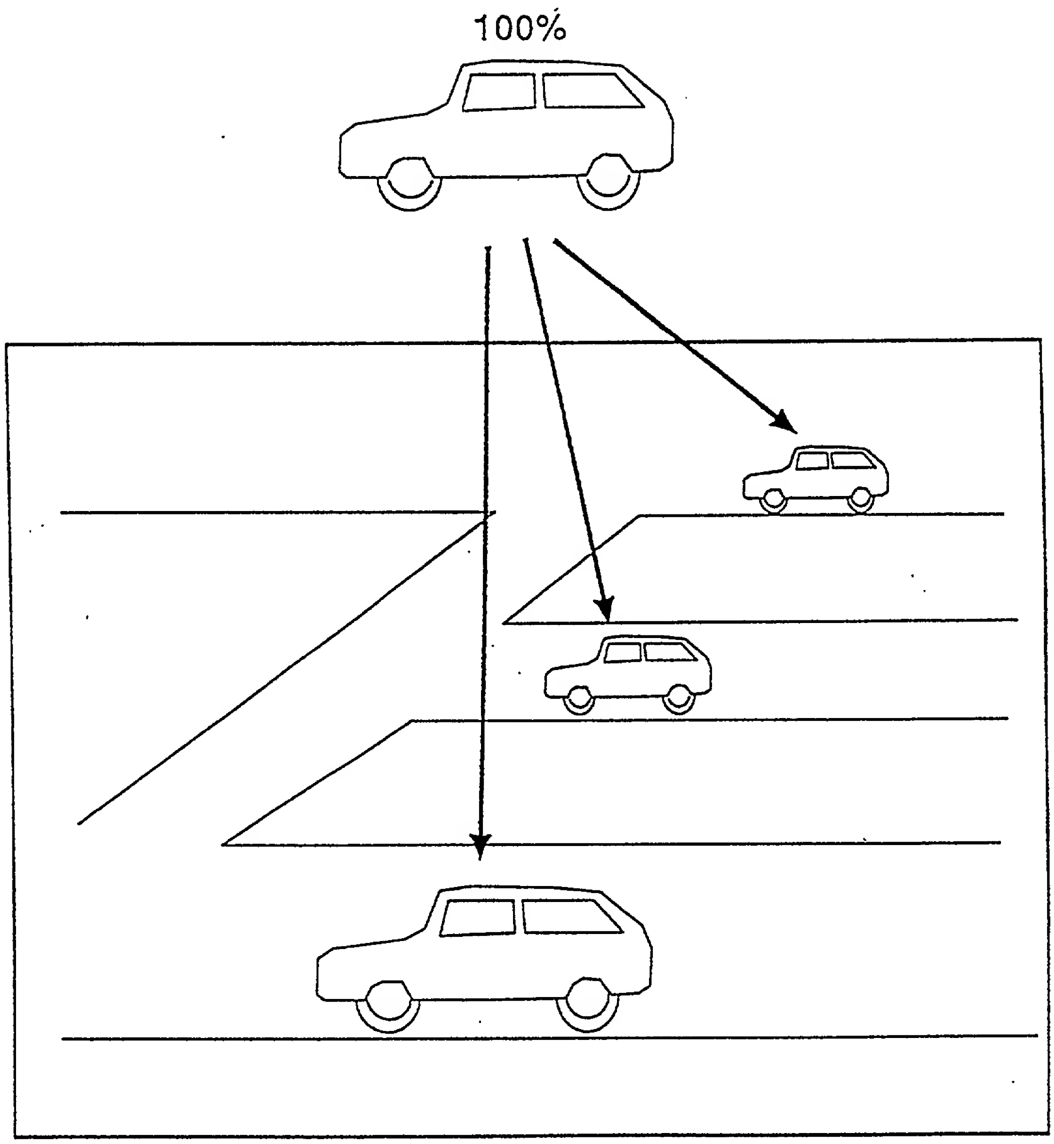


36%:66vertices



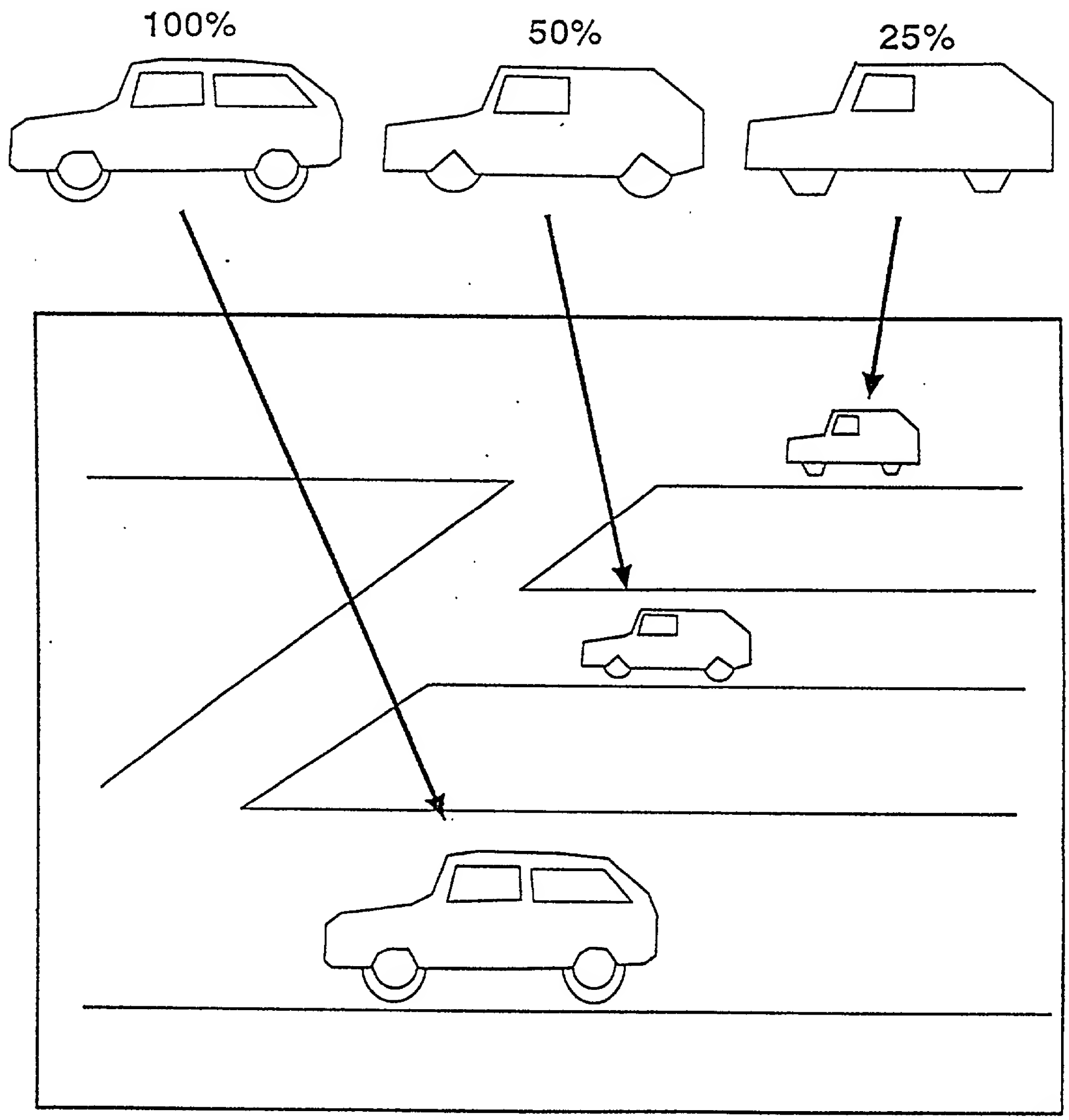
21. 6%:39vertices

Fig. 14



display

Fig. 15



display

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION
English Language Declaration

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled COMPUTER ANIMATION GENERATOR

the specification of which

(check one)
☒ is attached hereto.

☐ was filed on ______________________ as

Application Serial No. ______________________

and was amended on ______________________
(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent of inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)			Priority Claimed	
P07-348403 (Number)	Japan (Country)	18/12/1995 (Day/Month/Year Filed)	☒ Yes	☐ No
P08-273064 (Number)	Japan (Country)	24/09/1996 (Day/Month/Year Filed)	☐ Yes	☒ No
(Number)	(Country)	(Day/Month/Year Filed)	☐ Yes	☐ No

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

English Language Declaration

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

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Inventor's signature	Junji Horikawa — November 6, 1996 Date
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Post Office Address	c/o SONY-KIHARA RESEARCH CENTER INC. 1-14-10, HIGASHI GOTANDA SHINAGAWA-KU,
	TOKYO, JAPAN
Full name of SECOND joint inventor	TAKASHI TOTSUKA
Second Inventor's signature	Takashi Totsuka — Nov 7, 96 Date
Residence	CHIBA, JAPAN
Citizenship	JAPANESE
Post Office Address	c/o SONY CORPORATION 7-35, KITASHINAGAWA 6-CHOME, SHINAGAWA-KU,
	TOKYO, JAPAN